Planning for Bushfire Resilient Urban Design

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Resilience is often understood as the ability to “bounce back” from adversity, and has been used for some time in ecological and psychological settings. However, applying the concept to human settlements presents many challenges, even when considering a single risk source, such as bushfires. Fundamentally, the concept of resilience in its ecological meaning requires that a resilient species be one that has received multiple “shocks” over time, from which it has adapted, leaving it more able to withstand future shocks. This concept requires considerable modification if it is to be applied to the physical arrangements of human settlements as they relate to bushfire. Importantly, human systems of resilience *can* be improved by the development and application of collective knowledge. In terms of bushfire, there is currently limited empirical knowledge of urban design principles to improve resilience, despite the considerable energy focussed upon improving buildings’ ability to withstand radiant heat, and fire modelling. This paper uses the case of the Bendigo 2009 bushfire in Victoria, Australia. It considers why certain parts of the built-up area in Bendigo were more susceptible to bushfire-attack than others, as a base for development of key urban design principles to increase settlement resilience to bushfire. In particular, issues such as density, urban morphology, and distribution are considered. It is argued that particular settlement design elements are influential in determining the impacts of a typical bushfire on urban boundaries, and upon the resilience of settlements.

Key Words: Bushfire, Urban Design, Risk, Planning

INTRODUCTION

While governments have readily adopted resilience as a general term encompassing a number of interrelated policy positions, the ability to translate this to actual implementation programs presents many challenges. In the case of bushfire risks in urban edge settings, the number of dwellings and businesses at threat of bushfire attack is increasing as climate change affects fire risks, and increasing incursions into edge areas occurs, driven by population growth and sprawl (Buxton, Haynes, Mercer, & Butt, 2011). In this sense, the idea of resilience as “bounce back” from adversity seems to be of limited value, in that it ostensibly involves the assumption that repeated attacks from fire would lead automatically to increased resilience.

This paper seeks to consider more carefully the concept of resilience and human settlements, focussing on the hazard of bushfires. Moving beyond previously published work on this area, the paper presents a view of resilience that seeks to examine it in a way that is different from its traditional ecological, physics, engineering and psychological meanings. The concept requires modification for use in human settlements, such as those subject to bushfire threat. The Bendigo 2009 bushfire in Victoria, Australia is used as a case. First, the idea of resilience as it relates to planning is presented. Second, sub-categories of resilience are examined, as they relate to the case of bushfire, in particular focussing on the concept of resistance. The paper concludes by arguing that some settlement design elements impact upon aspects of resistance, in parallel with the processes of planning that respond and adapt to new information relating to bushfire over time. The next section briefly describes the Bendigo 2009 fire as a foundation for the subsequent sections.

THE BENDIGO 2009 FIRE

Bendigo is a regional city of 105,000 persons in Victoria, Australia, some 150 kilometres north west from the state's capital, Melbourne. The Bendigo fire of 7 February 2009 came within 2 kilometres of the city centre, causing alarm in an area generally considered to be well within the city's urban boundaries. The fire, which commenced shortly after 4:00pm, had travelled 4.7 kilometres in a south easterly direction pushed by gusty winds averaging 41 kilometres per hour, in highly dangerous conditions that included humidity of only 6%. It progressed via grasslands and into the crowns of trees, and included ember spotting some 2 kilometres in advance of the fire front (Teague, McLeod, & Pascoe, 2010).

At approximately 6:30pm, a southwesterly wind change occurred at 35km/h, driving the fire towards the northeast, leading to a long fire front of approximately 4.0 kilometres. After this wind change the gusty and erratic conditions led to some ember spotting occurring, resulting in several smaller spot fires to the northwest of the new fire front. After the wind change, the fire progressed unevenly to the north east, making its greatest overall "width" in this direction approximately 2.1 kilometres, until approximately 7:30pm, when the main part of the fire was considered contained.

The Bendigo fire resulted in one fatality, 41 injuries, and 341 hectares burned. A total of 58 houses were destroyed, with many more homes and properties damaged (Teague et al., 2010). This fire occurred in the context of the Saturday 7th February 2009 fires in which more than 2000 homes and 61 businesses were destroyed, with many more damaged. Approximately 430,000 hectares of land were burnt overall, and 173 lives were lost (Victorian Bushfires Royal Commission Interim Report, 2009). The background conditions that led to the fires include ten years of drought and over one month of record-breaking summer temperatures. In the days leading up to the 7th February fires, maximum daytime temperatures reached over 40 degrees Celcius on a number of occasions , culminating in a maximum of 45 degrees on the 7th itself (Bushfire CRC 2009). The next section examines resilience and considers it in terms of planning processes.

RESILIENCE AS A PLANNING PROCESS

It appears to be common for resilience to be assumed as a static quality of places and people. However, this view does not hold when one considers the dynamic and temporal nature of bushfires and the human systems that interact with it. Bushfires are a seasonal hazard for many human settlements located within Australian bushland settings (Emergency Management Australia, 2004; Ramsay and Rudolph, 2003; The Bushfire Planning Group, 2005). Since South-eastern Australia is in one of the most fire prone areas internationally (Buxton et al., 2011; March & Henry, 2007), (Hughes & Mercer, 2009); bushfire resilience is a key component in the ongoing sustainability of Australian settlements (Teague et al., 2010).

The widespread use of resilience as a term is now well documented, as are the many ways that it can be applied to various settings. The term appears to have its origins in rheology, physics and engineering, being used to describe the qualities of materials used in naval and other military design processes (Berkes, 2007; Hoffman, 1948). More recently, the term has received considerable attention since its innovative application to ecological processes by Holling (1972). Holling demonstrated that species in dynamic ecological systems that suffer (and survive) many "shocks" over time will have developed greater resilience than species in highly stable environments (Holling, 1973). Since that time, resilience has been applied in psychology to people and populations (Brown & Kulig, 1996), to economic systems (Briguglio, Cordina, Farrugia, & Vella, 2009) and to human settlements.

More recently, however, government policies have adopted the term as a kind of shorthand that seeks to encompass all features of places. For example, the 2011 theme of the Commonwealth

Heads of Government Meeting (CHOGM) is "Building National Resilience, Building Global Resilience". In Australia, the Council of Australian Governments (COAG) endorsed in February 2011 the National Strategy for Disaster Resilience. This document encourages a whole of government approach that sets goals and approaches to achieve resilience to disasters. It seeks to bring about communities that:

- function well under stress;
- successfully adapt;
- are self-reliant; and
- have social capacity

(Wilkins & McCarthy, 2011: 2)

For all the policy coverage, actual implementation of these strategies requires a transition from understanding resilience as a series of end-state characteristics, to determining how processes can be set in place to develop resilience over time, as a process in and of itself. If resilience is understood as a process, or as a "metaphor", as Norris et al (2008) argue, a community that is resilient is one which can draw on dynamic resources *after* an event to positively adapt. In this understanding, it is the process of improvement that represents resilience, rather than a particular end state (Norris, Stevens, Pfefferbaum, Wyche, & Pfefferbaum, 2008). This does not mean that the ability to withstand shocks is put aside. Rather, it is understood as one element of a community's overall capacities that might be built upon over time. The approach put forward by Norris et al can be described simply using 5 main temporal steps:

1. Pre-event functioning
2. Crisis event
3. Elements resist or are affected by crisis
4. Transient dysfunction

5a. Elements that resisted maintain pre-event functions
5b. Elements affected adapt and improve
5c. Elements affected have persistent dysfunction and vulnerability
(adapted fromNorris et al., 2008)

The understanding above suggests that conditions must be sought to achieve certain attributes in communities that will improve abilities to withstand shocks over time, as knowledge is developed. Key elements to examine empirically are: which elements of an urban system are resistant to shocks; which processes allowed improvements and adaptation to occur, improving resistance of elements; and, which aspects of the system did not allow improvement after a shock, or even reduce resistance capabilities. In a spatial planning sense, this can be aligned with procedural and substantive attributes of typical planning approaches that seek to review and improve characteristics of urban systems over time.

ELEMENTS OF URBAN DESIGN

It typically falls to urban design to deal with the scale of activity and concern that falls between built structures such as dwellings and overall settlement patterns. Urban design is charged with responsibility for creating, managing and improving urban places at this scale that yield benefits for individual and collective purposes (Carmona, Heath, Oc, & Tiesdell, 2003). A common catchphrase is for attention to be given to the "spaces between buildings" (Gehl, 2006), and the interactions between places, including safety and maintenance of all aspects of human life, even while health and safety in the place-making tradition of urban design has been less directly addressed. Tibbalds holds that places should be built to last and to be adapted (Tibbalds, 1988). Urban design needs to directly seek ways to have influence over, and to integrate understandings of bushfire risks into urban edge settings.

If an urban design approach is to be integrated with mitigation of bushfire risk, the nature of the hazard's interaction with settlements must first be established. Bushfires typically affect properties in the following ways: burning debris gets caught in or around buildings, and could be be blown by the wind (*ember attack* or *spotting);* radiant heat, which is affected by amount of fuel and the distance of the structure from the fire; direct flame contact; wind intensification of bushfires carrying burning debris, and may damage buildings such that airborne embers can get inside – breaking windows, blowing down doors etc. If it were possible to remove human structures and property from bushfire prone areas it would be an effective means of reducing bushfire risks. However, where settlements are pre-existing, or where trade-offs of fire risk against finding additional land for housing, interaction between settlements and fire is inevitable.

While a wide range of urban design matters might be considered in an assessment of fire impacts on the suburban edge, the elements that are under examination here were established previously as areas for further examination (March & Holland, 2011). These are: density; site coverage; and layout patterns. These elements are taken up in the following sections.

A FIRST STEP: MEASURING RESISTANCE TO FIRE IN BENDIGO

It is argued here, that as a first step to understanding resilience, it is necessary to determine empirically the characteristics of the fire-affected parts of Bendigo in terms of their ability to resist the impacts of the fire. To do this, three areas that were under threat case studies were selected from portions of the fire front and flanks, within a 200m distance, as having been urban interface areas that faced a threat from the fire.

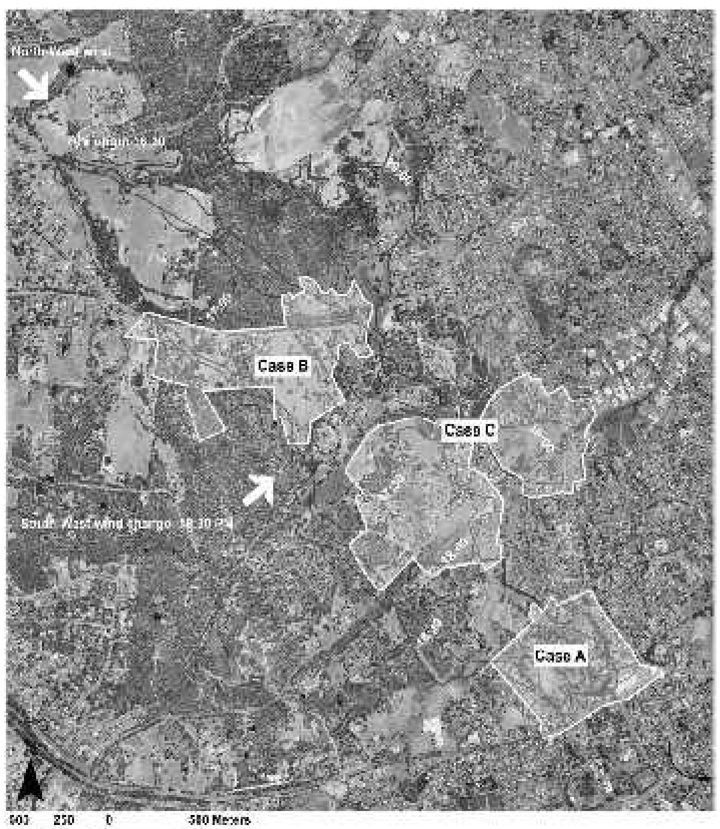

Figure 1 – Case Study Sites

Resistance to fire might be considered to entail a number of components: the ability to mobilise formal defence; the preparedness and characteristics of the local community; the physical characteristics of the structures themselves; and, the physical layout and arrangements of the roads and structures. This study seeks to examine the urban morphology of areas under threat and to consider how resistant these were to the fire as it affected them on the particular day in question. To assess this, classes of resistance were established from low resistance to high resistance: dwelling destroyed; property damage; undeveloped land damaged; and, unburnt. In keeping with 'Dwellings destroyed' were dwellings with more than 50% of the floor area destroyed and were usually not habitable as a result (Blanchi *et al,* 2006). Property damaged was classified as a whole value, defined as any developed property which experienced a form of fire damage, rather than a scaled percentage value of fire damage. Such a scale was outside the scope of this research. 'Undeveloped land damaged' was identified as any vacant lot that displayed any effects of fire damage. Unburnt was determined as lots showing 0% of fire effects damage.

Three sub-classes of lot size were established: semi-rural, large plot size; and residential. Semi-rural was defined as lots larger than 4000m^2. Large plot size was defined as within the area range of 800m^2-3999m^2. Residential was defined as lots less than 799m^2. These size ranges were formulated as they were indicative of the surrounding Bendigo region. Initially, the impacts of overall layout and arrangements were assessed by mapping analysis.

Density and its relationship with house loss was undertaken by way of Chi-square tests. Percentage tables and grouped bar charts were developed for cases A, B & C as well as the combined data set. This was used to graphically and numerically represent the trends in a simple form. Comparisons were then made between the percentage tables and the trends contrasted between the case studies and the previous Chi-square statistics. Site coverage was calculated by dividing the total lot coverage of a particular lot by the total lot area. Total lot coverage included dwelling, sheds and any concrete or paved surfaces such as driveways. However, water tanks, swimming pools and gravel paths were not included in the total lot coverage value. Analysis of *site coverage* and its relationship with fire impacts was undertaken by way of one-way ANOVA tests. Stacked box-plots displaying key data points were used to visually represent the relationship between the data found for Cases A, B & C. A one-way ANOVA test determined whether the three populations' means: dwelling destroyed; property damage; and, unburnt were equal, to test the two variations between the categories and to determine whether the groups are 'significantly' different in terms of resistance to fire.

ELEMENTS OF RESISTANCE

To understand the relationship between density and fire impact, density and burn penetration were displayed in cross tabulations. The distribution of data has been displayed on a grouped bar chart of density type and burn penetration level, summarised at Figure 2. One-way chi-squared tests have been undertaken for each case study in order to evaluate how 'close' these observed values are to those which would be expected from a hypothetically fitted model. Results were calculated for the combined cases; A, B & C, which is presented below in Figure 3 to provide a more complete view of the effects of density.

		Fire Penetration			
Density		**Dwelling destroyed**	**Property damage**	**Undev Land Damaged**	**Unburnt**
	Semi-rural	35.38%	9.23%	15.38%	4.62%
	Large plot size	23.45%	19.31%	4.14%	53.10%
	Residential	4.46%	9.38%	1.79%	84.38%

Figure 2: Cross tabulation of fire penetration vs. density for cases A, B & C.

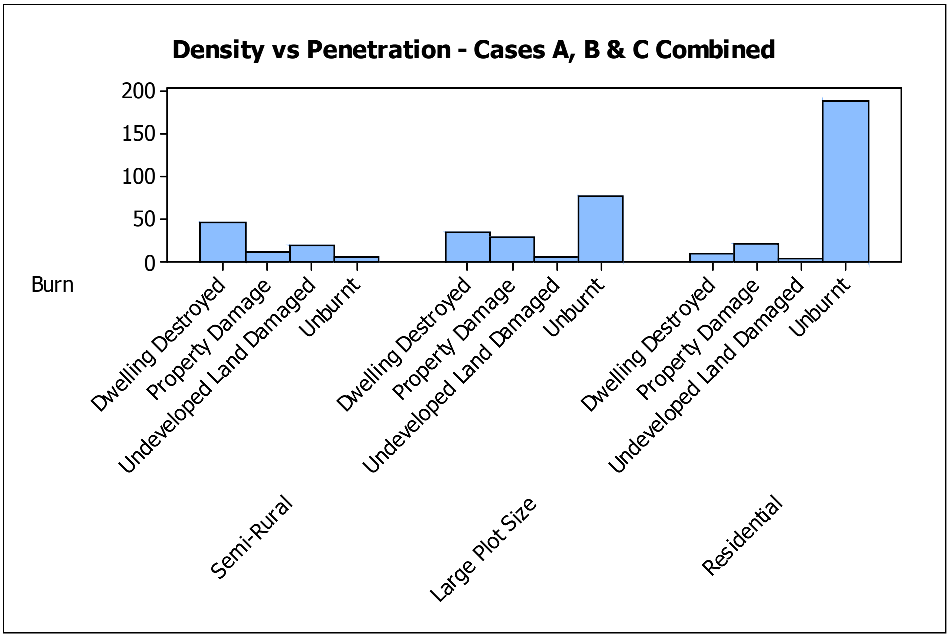

Figure 3: Grouped bar chart for density and fire penetration of cases A, B & C.

Residential properties in the study were predominantly 'unburnt'. The density category of 'semi-rural' had a proportionally significant percentage which remained unburnt. The combined chi-squared analysis uses the combined data and Minitab produced the following output for similar categories: Chi-Sq = 194.802, DF = 6, P-Value = 0.000. For the results the P-Value of 0.000 will be interpreted as $P < 0.001$. The Chi-squared test statistic is 194.802 with an associated $p < 0.001$. The null hypothesis is also rejected, since $p < 0.001$. The conclusion may be made that 'density' is associated with 'fire penetration'. In the category of 'dwelling destroyed', as the density increased from 'semi-rural' to 'residential' the observed damaged or destroyed values decreased.

The main outcome for the density analysis is that for lots classified as 'semi-rural' (greater than 4000m^2), there is an increased propensity to be subject to fire damage. The tests indicate that 89.29% of 'semi-rural' lots display effects of fire damage, with 32.14% of those being 'dwellings destroyed'. The inverse result was also found with properties classified as 'residential' (>800m2) having a decreased propensity to be subjected to fire penetration. Furthermore 84.3% of lots within cases A, B and C, classified as 'residential' were unaffected by fire penetration, compared with 'large plot size' and 'semi-rural' lots which remained 53.10% and 10.71% unaffected respectively. Finally, results of lots classed as 'large plot size' were situated in between 'residential' and 'semi-rural' in terms of fire penetration. 'Large plot size' lots experienced 46.9% burn penetration through either 'dwelling destroyed', 'property damage' or 'undeveloped land damaged'. These results show that in the case of the 2009 Bendigo Black Saturday Bushfire, that density had a highly significant association with fire penetration.

From the key findings, it is evident that lower density lots with lower site coverage percentage had a greater propensity to fire penetration. With a deeper look into the specific case studies it became apparent that these lots, classified as 'semi-rural', appear to act as "receiving" lots for fire, assisting the fire's progression.

The results established that of lots classified as 'semi-rural';100% in case A, 95% in case B and 82% in case C, demonstrated fire penetration through either 'dwelling destroyed', 'undeveloped land damage' or 'property damage'. The results for the three case studies combined found that 92.3% of 'semi-rural' lots demonstrated fire penetration through either 'dwelling destroyed', 'undeveloped land damage' or 'property damage'. Although results from the chi-square test from case A and B were inconclusive, tests from case C and cases A, B and C combined proved that statistically that there was a strong association between density and fire penetration.

Case C, which contains a number of varying urban densities, demonstrates the effects of 'low density' lots. As shown in figure 4, the fire body travelled in a south easterly direction, penetrating many of the 'semi-rural' lots within the case study boundary.

Insert Figure 4

Figure 4: Fire Penetration Case C

Large lots as fire receivers and conductors.

The role of larger lots as fuel islands and fire conductors also seem consistent for many lots classified in this study as 'large plot size'. 'Large plot size' lots displayed substantially less propensity to fire penetration when compared with 'semi-rural' plots, with; 47% in case a, 100% in case B , 44% in case C, penetrated through either 'dwelling destroyed', 'undeveloped land damage' or 'property damage'. Case B appears to be an extreme case, which contains predominately 'semi-rural' lots.

However, Case A shown in Figure 5 which includes lots with a wide spread of densities, provides an example of 'large plot size' lots appearing to encourage the fire's penetration, similarly to 'low-density' lots. As shown in figure 5, it is apparent that 'large lot size' lots appear to encourage the fire deeper into the built up area.

Insert Figure 5

Figure 5: Fire Penetration Case A

Lots most at risk from fire appear to be situated in isolation from dense 'residential' type housing, or were situated in loosely scattered pockets. Further it appears that lots of 'large plot size' are more susceptible to fire penetration when situated next to or surrounded by a lot of 'low-density'. It is also apparent that in this scenario, 'large plot size' lots which were penetrated often did not have the protection of the higher density 'residential' lots which will be discussed later. This again suggests that in the case of the 2009 Bendigo Black Saturday Bushfire, low density lots appear to have acted as receiving lots or fuel islands, encouraging the penetration of the fire.

As an inverse result to 'semi-rural' lots, lots with a relatively high density for the region, classified as 'residential' appeared in many cases to have acted as a barrier to fire penetration. The results established that of lots classified as 'residential'; 63% in case A, 100% of case B and 92% of case C remained unburnt. Furthermore with reference to figure 6, case study C exhibits the effects of 'residential' lots, in both the original fire body and the secondary fire to the north east, created through the effects of spotting.

Insert Figure 6

Figure 6: Fire Penetration Case C

Residential lots as barriers

Scale: 1; 3000

To understand the relationship between site coverage and fire penetration, average site coverage was calculated and presented for the combined case studies. One-way ANOVA tests were applied to the combined data to test the hypothesis that site coverage has a significant relationship with fire impact.

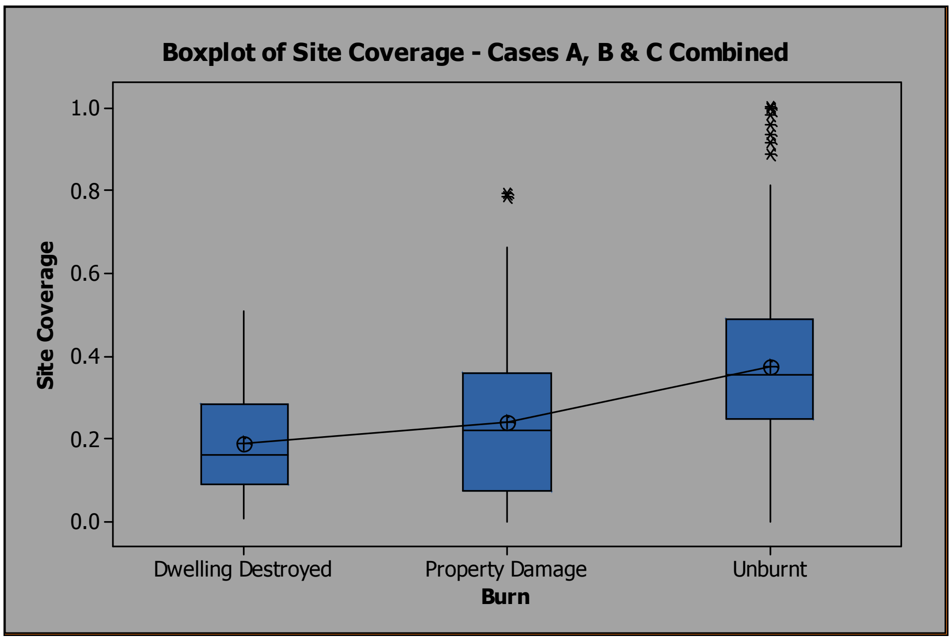

Figure 7: A comparison of site coverage mean values and inter-quartile range for cases A, B & C.

Figure 7 shows a box-plot representing the data set for cases A, B & C. The box-plot represents the mean percentage for site coverage. It suggests that an increase in average 'site coverage' was seen when moving from 'dwelling destroyed' to 'property damage' and then onto those properties which were 'unburnt'. This visual representation lends support to the theory that an increase in site coverage played an important role in decreasing risk to property in a fire event, at least in the case studied.

The combined data set is important in testing propositions formulated in this paper. As it incorporates all data from each of the case studies, it has the largest sample set which may reduce errors occurred in the analysis. For this combined data set, a one-way ANOVA is calculated by Minitab and produces a p-value of 0.000. While the output is 0.000, it should be reported instead as $p<0.001$. Hence as it is smaller than 0.05 it may be concluded that the test is significant at the 5% level and that the null hypothesis should be rejected. The conclusion from the output is that at least one of the fire impacts' categories' means is not similar for case A, B & C.

The calculation of Fisher Method grouping displayed the grouped information as follows; the category 'unburnt' is awarded grouping I, both 'property damage' and 'dwelling destroyed' are grouping II and 'undeveloped land damaged' is classified as category III. Means which do not share the same numeral are statistically significant. The two categories classified as within group II have two different mean scores for 'site coverage'; however they are not significantly different. Again this may be a result of the underlying variance in the scope of damage within the category of 'property damage'. Although there are two categories which share a grouping, the conclusions and results to be drawn from the output are strong. It can be concluded that there is a statistically significant difference between the site coverage for the properties which were unburnt compared to those which were damaged and destroyed. From the results of the combined data it can be concluded that a property with increased site coverage has a decreased likelihood of being effected by wildfire.

Key findings for Site Coverage show that for lots that were unaffected by fire penetration within cases A, B and C had an average site coverage of 37.2%. Of the lots within the three case studies that experienced property damage, 23.8% was the average site coverage. Lots within case A, B and C that had 'dwellings destroyed' showed average site coverage of 18.9%. Finally using one-way ANOVA testing on the combined data it can be shown that there is a statistically significant difference between site coverage for lots 'unburnt' compared to lots 'destroyed'.

The results show that the unburnt, 'residential' lots in case A, contained an average site coverage of 55.03%, 8.8% greater than all lots unburnt within case A (46.2%). Similarly unburnt, 'residential' lots in case C reported average site coverage of 36.09%, 2.08% greater than all unburnt lots within case C (34.01%). These site coverage percentages are relatively high for the area. Further, these average site coverage percentages are greater than that of the lots affected by fire, through either; 'dwelling destroyed' and 'property damage'. These results strengthen the idea that a greater site coverage percentage may reduce the likelihood of fire penetration. It also may be inferred that this decreased propensity for fire penetration, is a results of the lots acting as a barrier due to their greater site coverage. Possible reasoning may include reduced vegetative fuel loads across these lots of greater site coverage.

CONCLUSIONS - TOWARDS RESILIENCE IN SETTLEMENTS

Statistically it can be concluded that there was a significant difference between site coverage of lots for properties unburnt and those of which were damaged or had dwellings destroyed. This paper has suggested that resilience is best understood as a processes, where resilience is the ability to draw on dynamic resources after an event to positively adapt following Norris (2008). If this process of improvement is resilience, it was argued that developing understandings of elements of a community that can withstand shocks is a first step. Accordingly, the aspects of the Bendigo fire that represent *resistance* were examined.

Two independent variables were considered: density and site coverage, which turned out to have statistically significant relationships with the effects of fire resistance. Key findings for site coverage can be summarised as follows.

- Lots unaffected by fire penetration had an average site coverage of 37.2%, while those with property damage were 23.8% average site coverage, and "Dwellings destroyed" lots were an average site coverage of 18.9%.
- There is a statistically significant difference between site coverage for lots 'unburnt' compared to lots 'damage' and 'destroyed'.

In terms of *density,* key findings are that:

- Lots larger than 4000m^2 have an increased propensity to be subject to fire penetration, with 89.29% of 'semi-rural' lots displaying some negative effects of fire penetration, with 32.14% of those having dwellings destroyed.

- ‘Residential’ properties (<800m2) had a decreased propensity to be subjected to fire penetration, with 84.3% unaffected by fire penetration, compared with ‘large lot size’ and ‘semi-rural’ lots which were 53% and 11% unaffected respectively.

Care must be taken to ensure that it is understood that the results do not suggest that density or site coverage are causal. However, the results do indicate that in the case of the 2009 Black Saturday Bushfire in Bendigo statistically significant relationships exist between fire penetration, density and site coverage. These findings suggest that further research is necessary into the features of fire affected communities that are resistant to fire to inform future policy making.

On the basis of these findings that relate to resistance, the next steps are to consider whether reconstruction and future development pays heed to these findings as adaptation (Norris 2008). Planning systems need to include mechanisms to take into account these aspects, if resilience is to result.

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