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Development of a building resilience rating system for natural hazards

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ABSTRACT

Improvements in resilience, underpinned by an industry-accepted building resilience rating system will effectively generate a new, 'positive' industry that is based around inspections, assessments and retrofitting of existing buildings as well as the skilled review and rating of new designs and building projects. The rating assesses the likely functionality of a building after being exposed to a hazard, based on observations of building performance and research on building systems.

The Bushfire Building Council of Australia (BBCA) has developed a rating system from detailed post-bushfire building loss surveys, fire testing and engineering principles to promote awareness and engagement in bushfire-resilient design. The Cyclone Testing Station (CTS) has built a research-based assessment of the likely functionality of the building based on wind damage, water damage and storm surge damage. The model is built on the knowledge of the performance of building products and systems gained from detailed damage investigations by CTS teams following previous tropical cyclones, research and commercial testing programs and analysis of insurance data. These two systems are the basis of a rating tool that could address multiple natural hazards.

The resilience rating system is used to determine the resilience of new builds, by assessing the design, details, material choice, and proposed site. The rating considers performance in aspects not considered in the National Construction Code (NCC), which is concerned primarily with life safety; some materials and features that comply with the NCC may not be the most resilient options for some buildings.

The paper outlines engineering-based models for residential buildings (housing and strata developments) that can be used to estimate the likely performance and resilience of NEW and EXISTING properties in future natural hazards.

INTRODUCTION

Building regulations (i.e. codes and standards) coupled with insurance for assets provide resilience to the homeowner, business and government. Major changes were made to regulations, and designer and builder training for house construction due the devastation to the Australian city of Darwin following Tropical Cyclone Tracy (1974). Damage investigations following cyclones over the subsequent decades have shown that there is positive step change in performance for life safety robustness of housing built after the code changes (post-1980) across the cyclone regions of Australia, which is comparable to code improvements following Hurricane Andrew in the USA.

However, damage investigations and an examination of Australian insurance claims, following cyclones and bush fire impacts, reveals a high proportion of the losses in terms of cost of rebuilding or repair and loss of property's functionality. This raises questions as to fitness of purpose of our building construction, Codes and design practices, and durability or maintenance issues.

Engineering solutions exist to mitigate failures however damage surveys show lack of implemetation and maintenance. Smith *etal*., (2016) detail behavioural drivers for engaging and motiviating uptake of mitigation measures. In promoting mitigation to the homeowner, knowledge of risks associated with the hazard and clear actions to reduce risk are important drivers.

BUSHFIRE RATING DEVELOPMENT

Introduction

The Bushfire Building Council of Australia (BBCA) is developing a 'Star Rating System' (SRS) whereby existing and new properties can be given a star rating to indicate their relative level of vulnerability to bushfire attack. High star ratings correspond to low probabilities of loss, and conversely, low star ratings suggest a high probability of loss. The methodology can be best described as a notional probabilistic approach. The model presumes that no one is present at the property in the event of a bushfire and is therefore primarily concerned with the likelihood of loss of the house on the property. The SRS is aimed at enabling property owners to better understand their vulnerabilities with the view to taking remedial actions to reduce the risk of property loss.

The SRS is to be made available in two forms - an App whereby the property owner could undertake their own assessment, and an 'expert' program that will be able to be used by a more technically informed and trained assessor.

Bushfire attack on a house can occur by one of more of the following scenarios:

(a) Excessive radiation or flame contact from the bushfire flame front,

(b) Flame contact due to flames spreading to the house by continuity of low level fuel

(c) Ember attack on the house or on attached structures such as pergolas or carports

(d) The result of 'secondary' radiation due to items adjacent but separate from the house that may have been ignited primarily though burning embers.

Scenario (a) occurs with both both forest and grass fires and is mostly relevant for houses in the first row opposite the bush. Scenario (b) must be addressed though proper vegetation management and is partly via Scenario (d). Scenarios (c) and (d) are particularly relevant to woodland/forest fires which can generate embers due to burning bark and pine needles and which can travel substantial distances. It is generally accepted that most bushfire losses are associated with scenarios (c) and (d) which is the main focus of the SRS – although Scenarios (a) and (b) are not ignored. Scenario (c) is termed 'Direct' ember attack' whilst Scenario (d) as 'Indirect' ember attack.

The probability of loss of a house due to Scenario (c) is denoted as P_{DE} and that associated with

Scenario (d) as P_{IE}. The probability of loss due to Scenario (a) can be denoted as P_{BR}.

At its most detailed, the SRS requires the input of much information regarding the house being assessed, the location and size of items adjacent to the house and details regarding building structures on the adjacent allotments. The key inputs into the bushfire model are the Fire Line Intensity, Bark Hazard rating and set-back distance from the bushland. The Fire Line Intensity is expressed in Megawatts per m (MW/m) of the flame front, which in some cases can exceed 100 MW/m. The intensity of ember attack is a function of the Fire Line Intensity, the Bark Hazard and the distance from the bush. As would be expected, the intensity of ember attack increases with Fire Line Intensity but descreases as the distance from the bush increases. Therefore, all other factors being equal, houses more distant from the bush will be less likely to be lost. The SRS takes these factors into account.

For a house in the first row of houses opposite the bush the probabilty of PLOSS is determined as:

$$P_{LOSS} = 1 - (1\text{-}P_{BR}) \text{ x } (1\text{-}P_{DE}) \text{ x } (1\text{-}P_{IE})$$

but for other situations:

$$P_{LOSS} = 1 - (1\text{-}P_{DE}) \text{ x } (1\text{-}P_{IE})$$

Scenarios (c) and (d) and the determination of P_{DE} and P_{IE} are now considered.

Direct Ember Attack Mechanisms

The SRS considers that ember attack could result in loss of the building via the following ‘Paths’ which are treated as independent of one another – Walls (excluding windows and doors), Windows and Frames, Doors and Frames, Roof, Subfloor, Evaporative Coolers, Gas Supply Lines, Ventilation Pathways and Skylights.

One of more independent ember attack Mechanisms can be associated with each of these ‘Paths’. The paths and associated Mechanisms are detailed in Table 1 at the end of this paper. It can be noted from Table 1 that there are a total of 22 potential loss mechanisms. With the exception of Mechanism 20, which needs to be treated directly, the SRS method allows a probability of loss to be determined for each of these mechanisms taking into account the variables described in Table 1 (see dot points).

Determination of Probability of Loss for a Mechanism

It is assumed that the building is subjected to a high intensity ember attack as might be expected for a building located close to the bush and given a high fire line intensity. To illustrate the general approach used in determining the probabilities of loss associated with a particular mechanism, the approach used for Mechanism 2(a) (ember entry through General Roof) is described. This actually only applies to a house with a tiled roof. A ‘base’ house is defined having a given total plan roof area (Abr) and an estimated total tile gap area (Aob) that is asscociated with a ‘loose’ tile arrangement. The probablity of loss of this base house due to this mechansim *only* was then estimated by persons with a bushfire and fire engineering background assuming the presence of leaf and vermin litter in the roof cavity. This probability is denoted as P_b. For house situations which have a smaller or larger loose tile roof areas (Ar), the probablity of loss is determined from an expression of the form:

$$P = 1 - (1\text{-}P_b)^{(Ar/Abr)}$$

The expression illustrates that the larger the roof of a house, the higher the probability of loss, all other factors being equal. The effect of smaller gap areas (tighter tiles) modifies directly the nominated base building probablity of loss on the basis of the ratio to Aob. The presence of stored goods and combustible heating duct insulation, if present, are considered as additional independent sub-mechanisms such that the probability of loss for mechanism 2(a) is determined from an equation of the following form:

$$P_{2a} = 1 - (1\text{-}P_b)^{(Ar/Abr)} \text{ x } (1\text{-}P_{bb})^{(Ar/Abr)} \text{ x } (1\text{-}P_{bi})^{(Ar/Abr)}$$

Where P_{bb} is the probability of loss due to stored goods and P_{bi} is the probability of loss due to combustible heating duct insulation.

A similar approach has been used for assigning probabilities of loss to other mechanisms whereby values of probability of loss for a base situation have been assigned based on values estimated by persons with relevant fire engineering and bushfire expertise taking account of field data findings where available. The numbers in the model can be readily changed on the basis of new information.

Once all of the direct ember mechanisms have been considered the final probability of loss due to heavy ember attack is determined by combining the probabilities of loss (Pi) for each of the N mechanisms by the following equation:

$$P = 1 - (1-P_1) \times (1-P_2) \times \ldots\ldots\ldots\ldots\ldots(1-P_N)$$

The effects of Fire Line Intensity, Bark Hazard rating and distance from the bush are taken into account by multiplying P by a probability estimate based on historical loss data that takes into account these effects. This is how P_{DE} is determined.

Indirect Ember Attack Mechanisms

These mechanisms are illustrated by Figure 1 which shows that items or buiildings external from the house can be ignited and the resulting radiation can cause failure of the house windows or cladding.

Figure 1 Secondary Radiaiton from Ignited Adjacent Objects

Items considered include trailer boats, caravans, cars, woodpiles, canoes and kayaks, plastic bins and furniture, plastic water tanks, vegetation, retaining walls, storage sheds, fences and detached garages. The management of vegetation on the allotment is important both respect to vegetation type and proximity to windows. Also of significance (Figure 1) are the houses on adjacent properties if located too close. Each of the above items can be characterised by a radiator and once their distance to a point on the house is known, the radiation at that point is determined. If the radiation exceeds a limiting value for glazing or cladding then it is assumed that the house is lost and the probability of loss is equal to the probability of ignition of the item but reduced proportionately with distance from the bush according to the historical loss algorithm mentioned previously. Values for ignition are given for each of the items assuming a ‘heavy’ ember attack as for the direct ember attack model. In the case of houses on adjacent allotments or a detached garage, the probabilities of ignition are calculated.

Potential loss due to proximity of the many of the above items can be addressed by moving the items to an appropriate set-back distance. Other items, such as fences and plastic water tanks may need to be replaced with non-combustible items should the probability of loss be too high. Protection of windows against radiation by appropriate screens may also be an option in relation to exposure from fires in houses or buildings on adjacent allotments or from a detached garage on the same allotment. In the case of detached garages if these are too close, careful attention will need to be paid to ensuring that the garages are ember resistant and unlikely to be affected by adjacent items including vegetation. The model allows the assessment of detached garages to determine their probability of loss.

Outcomes from Model Application

Application of the model to a range of housing situations in proximity to the bush seems to demonstrate that great attention must be paid not only to house details but to the positioning of items adjacent to the house in order to achieve a high star rating. With respect to direct ember attack, dominant mechanisms (Table 1) appear to be mechanism 2b (roof ridge openings) especially where stored goods are in the roof cavity, mechanism 3 (debris in gutters and valleys) especially where there are overhanging or adjacent trees, mechanism 10 (interface of wall cladding with decks), mechanism 13 (interface of deck with windows and glazed doors), mechanism 18 (subfloor spaces) and mechanism 19 (evapourative coolers). Some of these mechanisms, where they are an issue, can be addressed through mitigation measures such as appropriate ridge sealing or venting, enclosure of decks, fixing of ember screens around evapourative coolers and enclosure of subfloor spaces. Such mitigation measures need also to recognise other functional requirements such as ventilation or enhancing termite resistance.

Table 1 Examples of Potential Loss Mechanisms – Direct Ember Attack

Path	Mechanism	Description
Roof	1	Heating of roof covering by embers/debris build-up - discounted
Roof	2a, 2b and 2c	Direct entry of embers into roof cavity via tiles roof (2a), steel roof ridges (2b) and eaves vents (2c). Takes into account: • opening areas (>2 mm) (and possible mitigation measures) • combustible contents in roof space (storage and ducts)
		•
Walls	6	Ignition of cladding due to mulch and debris (ground level) • cladding type • length of cladding
Walls	7	Ignition of cladding due to accumulated embes on horizontal fixtures (above ground) • cladding type • length of fixtures
		•
Windows and Frames	12	Embers ignite burning debris at ground level causing window frame failure • height of window above ground • horizontal separation from debris (width of ledge) • frame/glass/window seal arrangement
Windows and Frames	13	Interface of cladding with deck construction • frame/glass/window seal arrangement • deck construction (verticals, bearers and decking) • height of deck • surrounded deck corners • overhanging trees and 'fuel below deck
		•
Gas Supply	20	Avoid this issue by using the copper or protected pipework. Non-compliance is not assessed
Ventilation Pathways	21	Entry of embers via exhaust openings in walls or eaves e.g. dryer exhausts, exhaust fan outletts, kitchen exhausts, weep holes. • taken into account via other mechanism calculations (e.g. eaves vents, subfloors, etc
Skylights	22	Failure of skylight due to burning on top • skylight material • presence of debris (overhanging tree) • skylight screening

As far as indirect ember attack is concerned, a significant issue is the presence of annealed glazing in locations where it cannot withstand sustained radiation levels (< 5 kW/m^2) imposed by items located too close to the house – especially if those objects cannot be removed. Effective insulating bushfire screens may be required in such situations. Obviously glazing associated with houses in the first row of houses can also be subject to significant levels of radiation from the fire front. The advantage of substantial window shutters or screens is that they can also provide a further level of protection against physical impact from flying embers and debris that might be encountered closer to the bush.

Should a dwelling be potentially also exposed to extreme wind events, the building fabric, the enhanced wind resisting effects and the presence of window screens will clearly also enhance the resilience of the building to a bushfire event. The FORTIS housing designs provide engineered examples of these and other risk mitigation strategies. https://fortishouse.org/

Similarly, in comparing the method of resilience of building envelope to the hazard for both the BBCA SRS and the CTS rating metrics there are common question sets and themes.

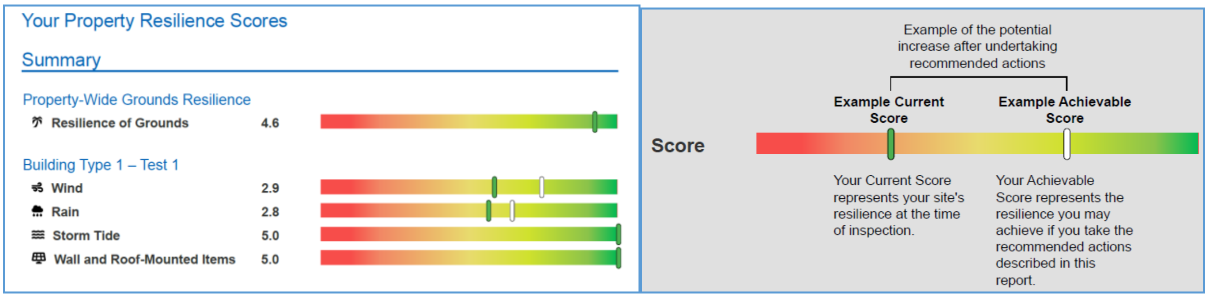
CYCLONE RATING FOR FUNCTIONALITY

Development

The CTS studied insurance claims of properties damaged from major cyclone impacts (Boughton etal., 2011; Boughton etal., 2017) in a project to investigate the drivers of loss to modern nominally building code compliant structures. The findings highighted a need increase awarness of aspects across building design construction and maintenance that hinder or promote resilience. The fedral government funded Stata title inspection program (STIP) https://stp1.hpc.jcu.edu.au/#/ was developed to:

- Provide an appropriately qualified/trained professional to carry out an examination of a strata property with regard to extreme weather vulnerability.
- Identify specific building issues that could lead to extreme weather damage and subsequent loss.
- Identify remediation options to address detected vulnerabilities for consideration by the Body Corporate.

‘Resilience’ in the context of the model developed is related to functionality, strength and robustness; resilience is the extent to which a building can remain mostly undamaged and functional during and after a cyclone. Five categories are used to assess the resileince of a property: grounds, wind, rainwater, storm tide, and ancillaries.


Your Property Resilience Scores

Summary

Property-Wide Grounds Resilience

Resilience of Grounds	4.6

Building Type 1 – Test 1

Wind	2.9
Rain	2.8
Storm Tide	5.0
Wall and Roof-Mounted Items	5.0

Your Current Score represents your site's resilience at the time of inspection.

Your Achievable Score represents the resilience you may achieve if you take the recommended actions described in this report.

Figure 2. Resilience scores for the aspects of functionality

Method

The model uses a number of steps to evaluate a resilience score as illustrated in Figure 3:

- The answers are used to give resilience rankings in each resilience category to the item addressed in the question (e.g. fixing type and spacing on roof flashings);
- The probability of survival with respect to specific issues (e.g. wind damage to flashings) is estimated;
- A number of different issues are combined to evaluate the likely performance of features (e.g. combinations of roof issues such as damage to cladding, fasteners, flashings, etc will be used to estimate the likely performance of the roof as a single feature of the building;
- The output resilience score is evaluated by combining all of the features within a resilience category. The combination is weighted according to the building geometry.

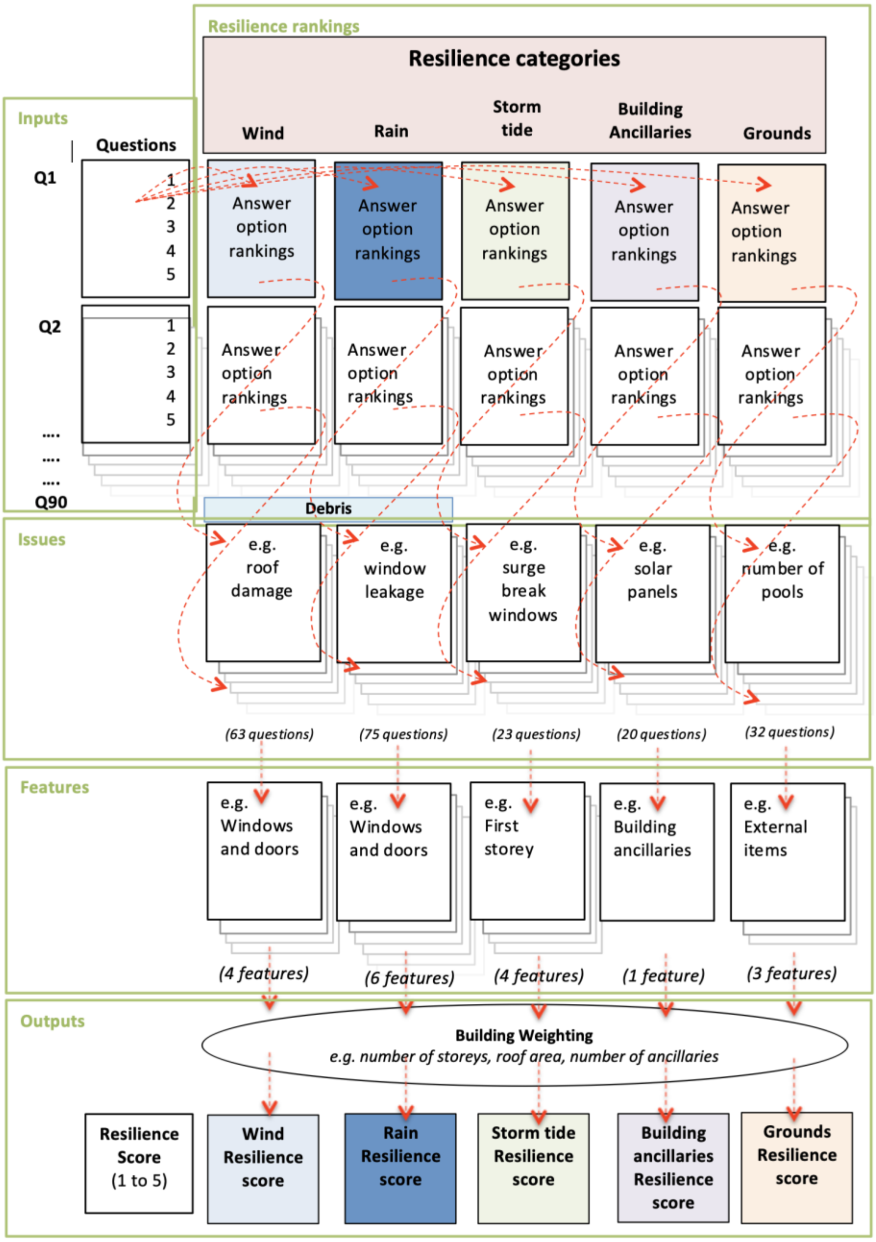


Figure 3. Flowchart for calculation of resilience scores

CONCLUSION

Benefits of a transparent building resilience rating extend beyond the potential for reduced premiums. The Rating has the potential for improving the resilience of the wider community through increased awareness. The survey of buildings will allow a comprehensive assessment of building performance and potential issues. Remediation of the identified building elements that may limit survival or amenity will result in a more resilienct community with lower damage losses.

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BIOGRAPHY

Dr David Henderson

David is the Chief Engineer of the CTS at James Cook University. David joined the CTS 30 years ago. He has broken everything from roofing screws to complete houses. David has conducted post-disaster damage investigations in Australia and overseas. He has developed vulnerability models for residential and commercial buildings. David is involved in Australian Standards committee for Wind loads on housing as well as Standards for Design, Testing and Installation of various building materials and elements.

Dr Ian Bennetts

Dr Ian Bennetts is a fire safety and civil engineer who works with SKIP Consulting and has a long interest in the behaviour of buildings in bushfire. This has involved working with the Bushfire Building Council of Australia and Homes Victoria having assisted in the development of a bushfire risk model for public housing. Formerly he spent 19 years at the Melbourne Research Laboratories of BHP where he headed up structural and fire engineering research. Following this he spent 6.5 years with Victoria University as a Professorial Fellow at CESARE and 9 years at Noel Arnold and Associates (risk management).

Kate Cotter

Kate Cotter is the CEO and founder of the Building Bushfire Council of Australia (BBCA). She established the organisation to develop collaboration between experts, industry, communities and governments to motivate and reward disaster and climate adaptation.

A/Prof Geoff Boughton

Geoff has a PhD in Structural Engineering for work on wind loads on housing. He is an Adjunct Associate Professor in the College of Science and Engineering, JCU and a Fellow of the Institution of Engineers and a member of both the Australasian Wind Engineering Society and the Australian Earthquake Engineering Society. He is a member of a number of Australian Standards Committees including AS 1684, AS/NZS 1170.2 and AS 4055. Geoff has led damage investigations following extreme wind events throughout Australia. Geoff is currently part of the team working on the North Queensland Strata Title Inspection Program, and other projects within the Pacific region.

Debbie Falck

Debbie Falck has worked with the Cyclone Testing Station as a research officer for over 15 years on projects to improve the resilience of buildings to severe winds and to investigate damage to buildings following extreme wind events in all areas of Australia. Debbie has investigated damage to buildings and houses following Cyclones Larry and Yasi in Queensland and George and Olwyn in WA, and has assessed construction practices in housing in cyclone-prone regions of Australia and the Pacific. Debbie is currently part of the team working on the North Queensland Strata Title Inspection Program.

Patrick Driscoll

Patrick Director of CTS and Project Manager for STIP. He is an Engineer graduating from James Cook University. Of recent years he has worked extensively in the delivery of digital business solutions, business analysis, and project management to a variety of businesses. Patrick is currently studying Urban Planning and Design at a masters level and has a particular interest in improving the resilience and repurposing of existing buildings.