Resilient Buildings: Informing Maintenance for Long-term Sustainability

Final Research Report

Part 1: Overview of losses from extreme events and building maintenance recommendations

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Research Project: P1.53 Resilient buildings: Informing maintenance for long-term sustainability

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Date: September 2018

OUTLINE OF THE FINAL RESEARCH REPORT

The Final Research Report of SBEnrc Project 1.53 Resilient buildings: Informing maintenance for long-term sustainability is presented in the following set of separate documents:

Part 1: Overview of extreme events and maintenance

Part 2: Maintenance and resilience of buildings for bushfire risks

Part 3: Maintenance and resilience of buildings for flood vulnerabilities

Part 4: Development of a maintenance prevention strategy to mitigate wind-driven rainwater ingress through windows and external glazed doors in social housing

This Part 1 of the Final Report includes:

(a) A report on natural disaster losses due to extreme events in Australia, along with an overview of emerging risks;

(b) A synopsis on the resilience and maintenance of buildings; and

(c) A set of overall recommendations along with suggestions for their implementation.

Further Information and other reports: http://sbenrc.com.au/research-programs/1-53/

ACKNOWLEDGEMENTS

This research has been developed with funding and support provided by Australia's Sustainable Built Environment National Research Centre (SBEnrc) and its partners.

Core Members of SBEnrc include Aurecon, BGC Australia, Queensland Government, Government of Western Australia, New South Wales Roads and Maritime Services, New South Wales Land and Housing Corporation, Curtin University, Griffith University and Swinburne University of Technology.

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EXECUTIVE SUMMARY

SBEnrc project P1.53 Resilient Buildings: Informing Maintenance for Long-term Sustainability aimed to examine the role of maintenance in making buildings more resilient to extreme weather events, cyclones/storms, bushfires and floods, using technical knowledge to inform policy and practice. The focus was on existing public buildings and the methodology was to look for gaps in current policy and practice. Part 1 examined the impacts of extreme events, other emerging risks and the relationship between maintenance and resilience.

Key recommendations include:

- Maintenance should be part of the design for durability. A maintenance scheme should be provided as part of the final design.
- A maintenance manual for each building including relevant as-built documentation should be compiled and made available for the people responsible for its maintenance.
- Routine maintenance inspection should be used to detect new emerging risks to buildings.
- Procurement frameworks for responsive maintenance should be developed. Also, the maintenance responsibilities of different parties should be established for whole-of-life value and sustainability.
- 'Build back better' should be followed for sustainable resilience and smart infrastructure with advanced digital integration used for effective and efficient maintenance.

The way to implement the above recommendations and recommendations in Parts 2, 3 & 4 is to create a 'Framework for specifying building maintenance', from which individual building maintenance manuals can be compiled from information provided in the framework.

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1 INTRODUCTION AND PROJECT SCOPE

1.1 Introduction

Resilience of buildings is a national objective in disaster mitigation. Often, maintenance is a missing link to improving the resilience of buildings in extreme events. The performance of buildings decreases over time and without effective maintenance their vulnerability to extreme events will increase (Pham et al., 2018). This SBEnrc project P1.53 Resilient Buildings: Informing Maintenance for Long-term Sustainability[1] aimed to: (i) assess the impact of maintenance on the resilience of buildings in extreme events, and (ii) identify opportunities for improving building resilience against those hazards. Given the complexities of the problem, the investigations in this project were restricted to: (a) low-rise buildings with a focus on public sector assets, and (b) the extreme events that cause the highest financial losses in Australia, such as high winds, floods and bush fires. The outcomes of this project are useful references to update the Australian national and state guidelines on building asset maintenance. Also, the project findings and recommendations will be beneficial in the reduction of damage and losses to building stock exposed to such natural disasters.

1.2 Project scope

Aim: Identify the contribution of maintenance in making buildings more resilient to extreme weather events.

Context: Use scientific knowledge to inform policy and practice.

Natural disaster/ extreme events: Cyclones/storms, bushfires and floods.

Buildings: Public sector assets in Australia – state governments of New South Wales, Queensland and Western Australia.

Research focus: (i) Griffith University research team to look at selected aspects of resilience of buildings for storm and cyclone exposure; (ii) Swinburne University of Technology research team to look at selected aspects of building resilience for bushfire hazards and flood vulnerabilities.

Methodology: Investigate research gaps and explore improvement opportunities in current policies and practices; mainly through literature reviews, industry consultations and workshops.

[1] http://sbenrc.com.au/research-programs/1-53/

2 NATURAL DISASTER LOSSES AND EMERGING RISKS

2.1 Economic impacts of extreme events

The summary of losses from extreme events reported in this section is based on data and information from: (i) Bureau of Transport Economics (BTE) 2001 report - the *Economic Costs of Natural Disasters in Australia* – which covers the 32-year period from 1967 to 1999*;* and (ii) an updated report by Handmer et al. (2016) from a National Emergency Management Project and RMIT University which covers an extended period of 1967 to 2013.

This updated report from Handmer et al. (2016) included the following significant changes:

- New approaches used to construct the database for: (i) reported losses, (ii) insurance with multipliers (as used in BTE 2001)
- A normalisation procedure – to make the estimate comparable over time based on the Consumer Price Index (CPI) as in BTE (2001) but also Gross Domestic Product (GDP) and population
- The inclusion of heatwave (and drought) as natural hazards – data is limited; significant in terms of fatalities but not so much on economic losses

The following extracts from Handmer et al. (2016) are of specific relevance to this project.

(a) A loss analysis by State and Territories in Australia (Figure 1).

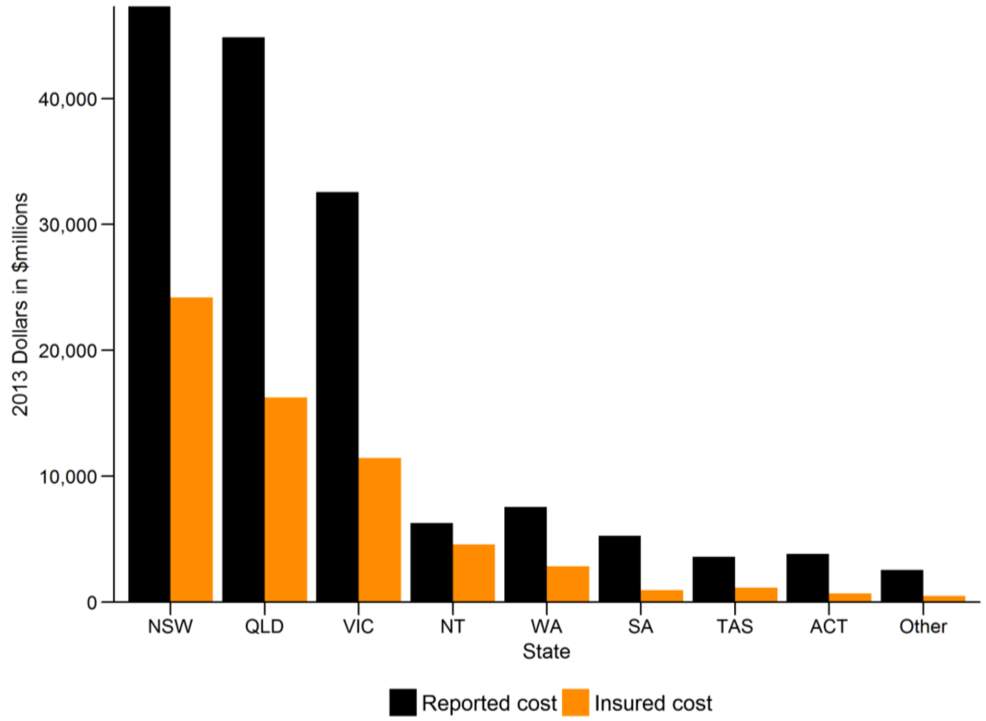

Figure 1. An analysis of losses due to extreme events in Australia (Handmer et al., 2016)

(b) A consolidated percentage overview of extreme events and losses for each Australian State and Territories (Figure 2).

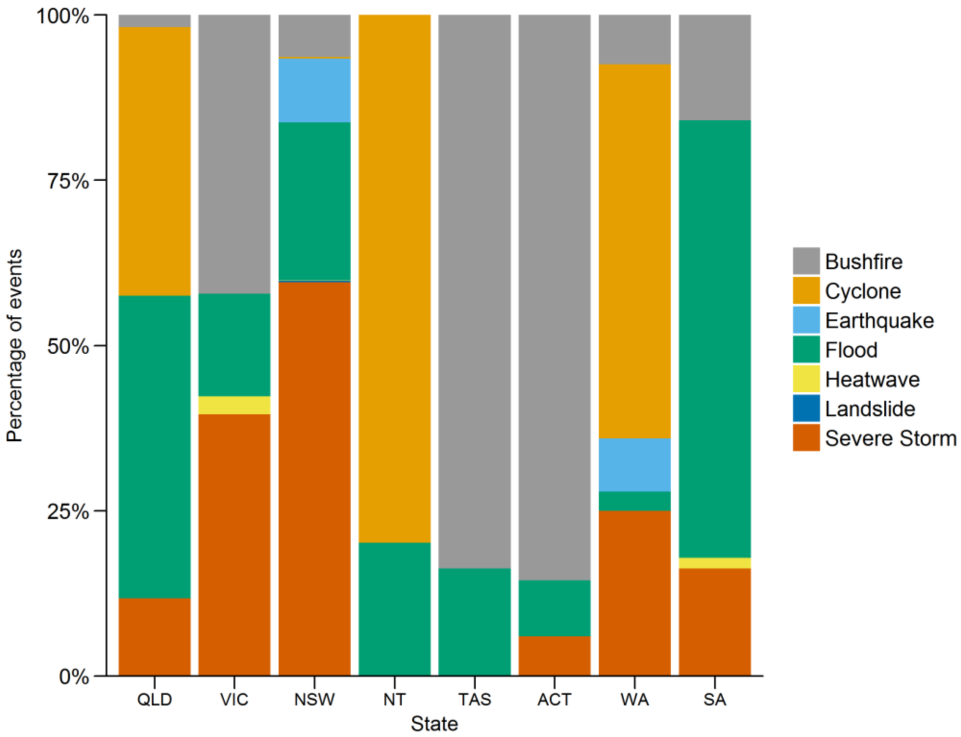

Figure 2. Percentage of extreme events and losses in Australia (Handmer et al., 2016)

(c) A consolidated summary of loss analysis by disaster type (Figure 3).

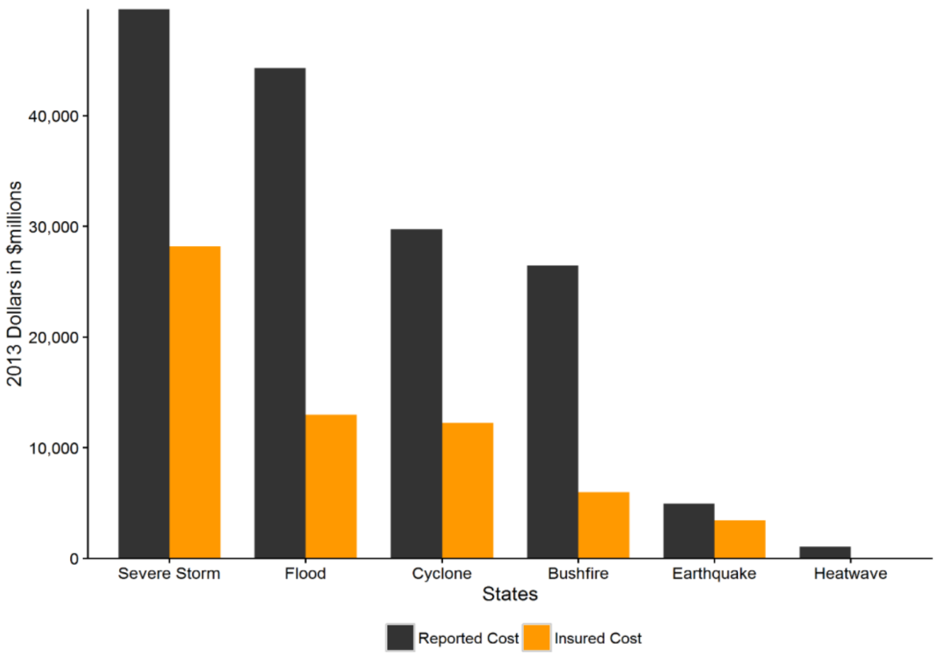

Figure 3. An overview of losses due to extreme events in Australia (Handmer et al., 2016)

(d) The increase of losses from bushfire extreme events (i.e. overall losses for the 1967 to 2013 compared with 1967 to 1999) is a noteworthy change from the previous report.

(e) Although potentially possible, no clear evidence is noted of a correlation between the impacts of planning and building regulations on the losses from extreme events

2.1.1 A basic analysis of losses from natural disasters in Australia

(a) The cumulative amount of total losses from natural disasters for the period 1967-2013 is AUD $171.5 billion (2013 price equivalent), in which the cost of death and injuries is $15.3 billion. The average of the total losses per year due to natural disasters for this period is around $3.65 billion.

(b) In the period 1967 to 2013, around 25% of the events cost more than $500 million and about 50% of the events cost more than $100 million each (Table 1).

Table 1. A basic summary of the cost distribution of losses from natural disasters (1967-2013)

Cost* of natural disaster losses	**< 10 million ($)**	**10-50 million ($)**	**50-100 million ($)**	**100-150 million ($)**	**150-500 million ($)**	**>500 million ($)**
Frequency ***(Cumulative Distribution Frequency)***	4 (0.014)	59 *(0.23)*	55 *(0.4)*	24 *(0.51)*	69 *(0.76)*	68 *(1.0)*

** Costs are in Australian Dollars.*

(c) The proportions of natural disaster losses in Australia during the 1967 to 2013 period were: (i) 32% from storms, (ii) 28% from floods, (iii) 19% from cyclones, (iv) 17% from bushfires, and (v) 4% from other extreme events. A set of summaries extracted from BTE (2001) and Handmer et al. (2016) are consolidated in Table 2 and Table 3 respectively.

(d) The highest impacting extreme events:

- Queensland, New South Wales and Victoria suffered the most losses from natural disasters, totalling 80% of the annual national losses in the 46-years report of Handmer et al. (2016); an increase in the annual average from 64% in the 32-years report of BTE (2001).
- From the Handmer et al. (2016) figures, storm losses are the major item for New South Wales; floods and cyclones are at the top for Queensland; bushfires and storms cause the most losses for Victoria; and cyclones for the Northern Territory and Western Australia.
- Victoria has seen the highest increase in recent losses from 8.6% (2001 BTE report) to 21.5 % (2016 Handmer et al. report), which are mainly from a surge in bushfires and storm extremes; the next highest increase in extreme event losses is for Queensland with a surge from 22.3% in the BTE report to 31.9% in the Handmer et al. report – mainly due to an increase in losses from floods and cyclones along with a reduction of losses due to bushfires in the region.

Table 2. The attribution of annual economic losses to extreme events within each State and Territory of Australia – 1967 to 1999*

Category of extreme event	**Australia wide annual economic losses***	**Losses within States and Territories in Australia***					
		New South Wales	**Northern Territory**	**Queensland**	**South Australia**	**Victoria**	**Western Australia**
Flood	29%	26.2%	5.7%	46.7%	39.2%	41.1%	4.1%
Severe storm	26%	40.5%	---	15.6%	35.1%	24.3%	17.7%
Tropical cyclone	25%	---	94.1%	0.2%	---	---	66.4%
Earthquake	13%	29%	---	---	---	---	4.7%
Bushfire	7%	3.5%	---	37.6%	25.8%	34.6%	7.1%

** The economic loss proportions are based on averages for the period 1967 to 1999 – as per information extracted from BTE (2001). No data available for Australian Capital Territory.*

Table 3. The attribution of total disaster losses to extreme events in Australia – 1967 to 2013**

State/ Territory	**Flood (%)**	**Storm (%)**	**Cyclone (%)**	**Bushfire (%)**	**Total^^ (%)**
Victoria	3.6 (3.5) ^	9.0 (2.1) ^	0	8.9 (3.0) ^	21.5 (8.6) ^
New South Wales	7.2 (12.9) ^	16.8 (18.2) ^	0	1.8 (1.8) ^	25.8 (32.9) ^
South Australia	1.6 (1.6) ^	0.4 (1.47) ^	0	1.2 (1.1) ^	3.2 (4.2) ^
Western Australia	0.1 (0.2) ^	1.2 (1.0) ^	2.7 (3.8) ^	0.4 (0.4) ^	4.5 (5.5) ^
Queensland	14.4 (10.3) ^	3.8 (3.5) ^	13.1 (0.04) ^	0.6 (8.4) ^	31.9 (22.3) ^
Tasmania	0.4 (0.6) ^	0	0	1.9 (1.0) ^	2.3 (1.6) ^
Northern Territory	0.8 (0.8) ^	0	3.2 (12.3) ^	0	4.0 (13.1) ^
Australian Capital Territory	0.2 (0) ^	0.5 (0.07) ^	0	2.2 (0.03) ^	2.9 (0.1) ^
Total^^	28 (30) ^	32 (26) ^	19 (16) ^	17 (16) ^	96 (88) ^

*** The information on losses for the 46-year period (1967 to 2013) is extracted from Handmer et al. (2016)*

^ The figures in brackets are extracted information on losses for the 32-year period (1967-1999) as per BTE (2001)

^^ The total excludes other extreme events such as earthquake

2.2 Emerging risks

New risks to building infrastructure can arise from various sources such as changes in construction practices, new materials/products and climate. Current research on climate change indicates that extreme weather events are likely to be more intense. However, available data and models are not adequate to robustly quantify the changes in terms of frequency and intensity. Regular maintenance inspections and updating of building records could be useful to detect a range of emerging risks related to the resilience of buildings.

Some examples of emerging risks:

- Leaky house syndrome (water trapped inside wall spaces causing decay)
- Condensation in living spaces due to the tight sealing required for energy efficiency
- Ground swelling affecting footings and foundations
- Bushfire occurrences in certain regions can enhance subsequent flooding risks due to changes in terrain and vegetation
- Heatwaves and drought can impact construction, building stock and the built-environment
- Large hailstones and serious hail damage to properties have ripple effects on building resilience; e.g. broken tiles and water ingress from the roof
- The effects of multi-hazard combinations and resultant short-term and long-term effects on resilience

2.2.1 A case study of the emerging risk – Leaky building syndrome

Certain types of construction, particularly for walls, allow moisture or water to collect within the system but do not provide for relevant drainage and ventilation. Under this condition, the moisture/ water is trapped with significant potential for fungal growth and rapid increase of rotting/decay.

This so-called 'leaky building' problem occurred in New Zealand (NZ) in timber-framed buildings constructed from 1994 to 2004, primarily related to the decay of timber. The consequences are that some buildings became structurally inadequate because of rotting and some became unhealthy to live in due to fungal growth. Around 42,000 buildings were affected, the majority being apartments, houses and school buildings. The cost of repair was estimated as $11.3 billion (New Zealand Herald 22 December 2009).

A similar problem occurred in early 1980 in British Columbia, Canada. The damage estimated in that region was CAN$4 billion.

Fungal growth on the surfaces of habitable spaces can also happen as the results of other causes, such as condensation if the house is sealed tight and there is a lack of ventilation. This is a noteworthy emerging risk for current construction, as it can be an unintended consequence of energy efficiency requirements. It should not be considered as a 'leaky building syndrome'.

Damp internal surfaces could also result from leaking pipes or heavy rains. These should also not be considered as 'leaky building syndrome'.

2.2.1.1 What causes leaky building syndrome?

Traditional constructions such as brick veneer or weatherboard cladding are not likely to have the problem of leaky building syndrome since the systems do allow any water in the wall cavity to be drained out. Changes in construction techniques and materials is considered as the main cause of the problem; for example, the increased use of 'monolithic cladding systems' such as fibre cement sheet and externally insulated plaster systems that allow the water into the cladding system but do not allow it to dry out. Another contributing cause was the change in NZ regulation that allowed untreated timber in the construction of timber framed walls. Timber was previously required to be treated against biological attack.

2.2.1.2 What to look for and where to look?

The Government of New Zealand[2] has provided the following lists of what to look for and where to look for signs of problems with weather tightness.

- What to look for:
  - Sagging of ceiling lining
  - Corrosion of fixings
  - Uneven floor surface
  - Mould or fungi
  - Musty smell
  - Swollen materials such as skirtings and architraves
  - Staining or discolouration of materials or surfaces
  - Staining and rotting of carpets or rusting of carpet fixings
- Where to look:
  - Flat roofs or roofs with parapets
  - Roof to wall junctions
  - Pergola and handrail fixings
  - Flashings to windows and penetrations
  - Decks over living areas
  - Balustrade to deck or wall junctions
  - Bottoms of claddings
  - Level of ground outside is higher than inside floor level

These are signs of weather tightness problems. To identify leaky building syndrome, it will be necessary to examine the construction method and eliminate other causes.

2.2.1.3 Could it happen in Australia?

Construction techniques and materials used in NZ and Australia are very similar. The weather in NZ is probably colder and wetter but there is no reason why the problem could not occur in Australia. Climate change makes it more likely for Australia as extreme events such as floods and cyclones could lead to a potential ripple effect and cause water/moisture ingress and leaky syndrome in some Australian States/Territories. There is anecdotal evidence that it has already happened, mainly through newspaper and TV reports. The building industry and the building regulators have understandably remained largely silent on the subject.

2.2.1.4 What to do?

The signs of water penetration problems can be observed during regular maintenance. Within the context of this project, a checklist can be prepared and included as part of routine maintenance. If the problems are detected early, the cost of repair will be much less than otherwise.

[2] https://www.building.govt.nz/resolving-problems/resolution-options/weathertight-services/signs-of-a-leaky-home/

The main problems are in the details for design and installation; the NZ building code and BRANZ provide lists of typical details to avoid the problems. These should be promoted as guidance for Australian designers.

2.2.1.5 Leaky building syndrome case study conclusion

Leaky building syndrome is an emerging risk to Australian buildings. Maintenance (in terms of regular inspections) may be able to detect the problem (through signs of lack of water tightness), but further work is required to identify the problem as definitely leaky building syndrome.

3 RESILIENCE AND MAINTENANCE OF BUILDINGS

3.1 Basic concepts

(e) **Extreme events**: these include cyclones, bushfires, floods and droughts which are *natural phenomena* and become disasters only if they cause severe impacts on a community in terms of life and/or property losses. The frequency and extent of these extreme events are influenced by climate change effects.

(f) **Community resilience:** the ability of a community to function after an extreme event. It implies the survival and recovery of the people and supporting infrastructures such as buildings and lifeline/utility systems; e.g. electricity and water supplies, and communication and transport systems. Australian Governments have declared improving national disaster resilience as a national objective (Council of Australian Governments (2009), *National Disaster Resilience Statement*).

(g) **Building resilience:** the ability of buildings to survive and to be restored after extreme events. It is not primarily about human safety, which is a separate issue. However, building resilience is an important component of community resilience because of the need for shelter and because many human activities take place in the built environment.

(h) **Maintenance:** activities undertaken while the buildings are in use to keep the building performance at a level safe and acceptable to the users. Maintenance activities include periodic and post-event inspections, repairs, replacements, refurbishments and retrofits.

3.2 About maintenance

3.2.1 Design for maintenance

Maintenance should be considered as part of the building durability performance design. Maintenance is a 'combination of all technical and associated administrative actions during the service life to retain a building or its parts in a state in which they can perform their required function' (ISO 6707-1:2017). According to ISO 15928-3:2015, a maintenance schedule is a key component in the description of structural durability performance. Different strategies for maintenance may be adopted depending on how the building is designed for durability (ABCB, 2003). Thus, maintenance should be considered in the design phase rather than left as a post-construction consideration.

3.2.2 Maintenance and the National Construction Code (NCC)

The Australian National Construction Code (NCC) currently contains no maintenance provisions as these are principally deemed as post-construction activities. This is a policy decision from the States and Territories (S&T). Maintenance is considered as a S&T responsibility in Australia.

3.2.3 Types of maintenance

In general, there are three types of maintenance activities:

(a) Maintenance of essential safety measures – these are mandatory for all S&Ts in Australia. All S&Ts have developed their guidelines for the maintenance of essential safety measures.

(b) Maintenance for habitability aspects such as aesthetic and comfort – these are generally carried out by the building owners or facility/property managers or occupants.

(c) Preventative maintenance for long-term resilience and mitigation – this is the main subject of this report.

3.2.4 Other salient points about maintenance

(a) **Queensland Department of Housing and Public Works, Building Maintenance Policy, Standards and Strategy Development (2017):** A suite of maintenance management framework documents is available online[3] containing: (i) Framework policy, (ii) Guidelines to complement the policy and (iii) Policy advice notes on specific emergency and maintenance matters.

(b) **Performance-based design**: Maintenance of performance-based design is problematical; especially in replacement with new products.

(c) **Non-standard/obsolete components**: Maintenance of non-standard novel or obsolete components is a difficult challenge. Disruptive technologies such as 3D printing could provide potential remedies, but these are currently costly and not feasible to all customers.

(d) **Software:** There is a variety of facility management software available involving maintenance. One example is *CTS ResiST,* developed to support 'asset management decisions by providing options for consideration in developing mitigation strategies to improve building resilience'. This was designed for existing non-residential buildings in wind regions A, B and C in Australia[4]. It is essentially a condition assessment tool that can be used on specific buildings. Many software options have concerns/issues, such as interfacing requirements, interoperability issues and version compatibility.

(e) **Maintenance manual:** There is generally no maintenance manual for buildings. While there is considerable information on building maintenance, there is no single source of reference to inform the users, particularly on condition assessment or preventive maintenance for wind, flood and bushfire.

(f) **International practice**: Building resilience of nations and communities to disaster is a United Nations goal for UNISDR (UN International Strategy for Disaster Reduction) since 1989. The current actions are based on Sendai Framework for Disaster Risk Reduction (2015-2030) (UNISDR, 2015). The Sendai Framework, in particular, emphasises the need for improved understanding of the risk exposure, the vulnerability of buildings and the hazard characteristics. Most of the UNISDR work focusses on developing countries, whose building vulnerability, hazard characteristics and risk exposure are very different from developed countries such as Australia. The work of this SBEnrc project followed the general principles of the Sendai framework; i.e. we looked at the risk exposure, the vulnerability of buildings and the hazard characteristics in examining the role of maintenance for long-term resilience.

(g) **Responsive maintenance with reliable relational contracting and partnering:** The British Research Establishment (BRE) report by Prior and Nowak (2005) highlighted that generally only 32% of the total building repair cost is spent on making the repairs and the remaining 68% is usually spent on: (i) producing tender documents; (ii) comparing prices (where not covered by a schedule of rates); (iii) placing orders; (iv) checking work in progress; (v) checking work on completion; (v) measuring completed work quantities; (vi) raising invoices; (vii) validating invoices; and (viii) negotiating discrepancies. Efficient and more resilient building stock in the public sector could be achieved through effective procurement arrangements of responsive maintenance with relevant partnering and alliance frameworks.

[3] http://www.hpw.qld.gov.au/FacilitiesManagement/BuildingMaintenance/MMF/Pages/Default.aspx

[4] AS/NZS 1170.2:2002 Structural design actions – Part 2: Wind actions, Australian/ New Zealand Standard.

3.3 Shergold and Weir report on the building regulatory system

3.3.1 General

In 2018, Shergold and Weir (2018) reported to the Australian Building Ministers Forum on the effectiveness of compliance and enforcement of Australian building regulatory system. The report was initiated as a result of the Lacross fire in Melbourne (November 2014) and Grenfell fire in London (June 2017).

The report's key findings were:

- Serious compliance failures
- Incompetent practitioners
- Inadequate documentation
- Weak oversight

Twenty-four recommendations were made including on the following topics:

- Registration and training of practitioners
- Roles and responsibilities of regulators
- Inspection regimes
- Post construction management
- Building product safety

3.3.2 Recommendation 20 – Post-construction management

The Shergold and Weir report referred to 'Commercial buildings' but its recommendations are relevant to all buildings.

Recommendation 20 of the report is relevant to maintenance:

The problem identified: 'a full set of final documents … is not usually collated and passed on to the owner … makes it difficult … to verify how decisions were made and … safety systems are properly maintained over the life of the building'

Recommendation: A building manual in digital format required to be provided and to have:

- as-built construction documentation
- maintenance requirements
- assumptions made in performance solution
- building product information
- conditions of use

3.3.3 Comments

The Shergold and Weir report is about new commercial buildings. For existing buildings, the recommendation (in Recommendation 20) of a specific building manual for each building still merits consideration but with some restriction on information relevant to maintenance to make it feasible.

4 OVERALL RECOMMENDATIONS OF PROJECT P1.53

4.1 Recommendations

This project has developed three other research reports (i.e. Part 2, Part 3 and Part 4) and an industry-focussed report. A set of overall recommendations from the project are listed in this section. Further recommendations specifically related to bushfire, flood and wind-driven water ingress issues are included respectively in Parts 2, 3 and 4 of the research report.

4.1.1 Recommendation 1: A maintenance schedule should be provided as part of the design for durability.

Consideration of maintenance during the design stage has many benefits including:

(i) It could allow different strategies for maintenance to be considered as part of service life planning (e.g. replacement of parts and the frequency of inspection)
(ii) It could facilitate maintenance actions by providing safe and easy access to components that require maintenance

4.1.2 Recommendation 2: A maintenance manual for each building should be made available for the people responsible for its maintenance.

Public building assets are wide ranging and diverse. Each building is exposed to different kinds and levels of hazards that will require different kinds of maintenance actions. This is particularly relevant to public assets where personnel changes make it difficult to track how decisions are made and systems are maintained over the service life of the building.

4.1.3 Recommendation 3: As-built documentation should be made available for maintenance purposes.

It is difficult to maintain buildings without as-built documentation. While design documentation is generally available, as-built documentation is difficult to compile because many changes are made during construction that are difficult to keep track of.

4.1.4 Recommendation 4: Routine maintenance inspections should be used to detect new emerging risks to buildings.

For public assets, routine maintenance inspection reports used to initiate maintenance actions can also be used to detect signs of emerging risks. This should only be used as a preliminary scan to initiate further investigation, as the causes of emerging risks are often complex.

4.1.5 Recommendation 5: An appropriate procurement framework for responsive maintenance should be developed.

Developing appropriate procurement arrangements with suitable partnering/alliances and frameworks for responsive maintenance should be considered to enhance the efficiency of outcomes and add value. Responsive maintenance might be through employing performance specifications-based organisation of direct labour and/or contractors. For example, a framework of performance-based target cost alliances with appropriate pain and gain sharing is relevant for long term maintenance of certain assets or earmarked key components of building stock.

4.1.6 Recommendation 6: Build back better for sustainable resilience.

The 'build back better' for sustainable resilience concept (UNISDR, 2017) should be integrated in repair, renovation, retrofit and reconstruction situations. Any occurrence of repair/renovation/retrofit/ reconstruction provides valuable opportunities such as: (i) potential foolproof prevention of subsequent mitigation requirements for resilience of buildings against disaster risks; and (ii) possibilities for enhancing the sustainability futureproofing.

4.1.7 Recommendation 7: Establish maintenance responsibilities for whole-of-life value and sustainability.

Mandatory and non-mandatory responsibilities aimed at whole-of-life value and sustainability should be established for the property owners, occupants and stakeholders. For this recommendation, critical requirements include: (i) improved understanding (e.g. through extensive research) on lifecycle costs of all common building types and key components; (ii) appropriate regulatory and governance frameworks; (iii) checklists and guidelines for non-mandatory responsibilities of different parties; (iv) relevant arrangements for education and training in this regard. Useful guidance on life cycle costing of maintenance is available – e.g. in BS 8544:2013

4.1.8 Recommendation 8: Develop smart infrastructure with advanced digital integration for efficient maintenance and effective resilience.

Developing smart infrastructure with advanced digital integration should be considered to enhance the effectiveness of maintenance activities and efficiency of resilience outcomes. The key requirement identified in this regard is integration of Building Information Modelling (BIM), facility/ asset management systems, embedded real-time condition monitoring hardware and software, smart analytics and intelligent systems with block-chain cryptography.

4.2 Implementation of recommendations

One way of implementing the above recommendations is to create a '**Framework for specifying building maintenance'**. Specifying maintenance involves work at all levels from design and construction to specific maintenance actions. It can be made to cover new buildings and/or existing buildings involving one or all three types of maintenance (essential safety measures, habitability and preventive). An individual building manual for a specific building can be compiled from information provide in the Framework. All the recommendations in Parts 2, 3 and 4 of this Final Research Report can be incorporated as part of the Framework.

For example, a non-mandatory framework for existing buildings may contain the following components:

(i) Protocol for compiling a specific building maintenance manual.
(ii) Protocol for regular building inspection and reporting.
(iii) As-built record of elements that may require maintenance or may be affected by maintenance actions.
(iv) Maintenance schedule, including the required maintenance level and frequency.
(v) If a performance-based design was used, assumptions made in deriving the performance solution (relevant to maintenance).
(vi) Building product information (relevant to maintenance).
(vii) Maintenance checklists (if relevant) for:
  - Earthquake
  - Bushfire
  - Flood
  - High winds and cyclones
  - Water tightness of openings
  - Hailstorm

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