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# A risk prioritization method for residential buildings with combustible cladding

## A Report for Cladding Safety Victoria

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# Contents

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# 1 Introduction

The Victorian Government established the agency *Cladding Safety Victoria* (CSV) in 2020. CSV is responsible for managing a program for the removal of flammable exterior wall cladding systems ("combustible cladding") from residential buildings in Victoria. These materials are Expanded Polystyrene (EPS) and Aluminium Composite Panel (ACP). CSV plans, funds and oversees the removal of the wall systems and the replacement of these with materials that are considered safer. CSV's scope is limited to what is known as *Class 2* residential buildings and further where these buildings have multiple independent occupants and are greater than two storeys in height.

EPS and ACP have been popular materials for the exterior of buildings in the period from about 2000. They find use as sheeting material as well as the basis of decorative architectural elements. EPS and ACP can fuel fast-moving and intense façade fires on buildings. This has been demonstrated by incidents worldwide including the Grenfell Tower disaster in London in June 2017. In Victoria there have been notable incidents over time including façade fires at buildings known as *Neo* and *Lacrosse* in Melbourne's CBD.

The removal and replacement of flammable exterior wall cladding systems is expensive and there are hundreds of Class 2 buildings in Victoria which are candidates for funding under the program that is administered by CSV. The planning and execution of removal and replacement takes time and resources. It is impractical to address all candidate buildings simultaneously. Because some buildings pose more risk than others, both the *selection* of buildings to receive treatment of the flammable cladding and the *sequencing* over time of undertaking the changes are of importance. Amongst selected buildings those with more risk should be addressed (retired) earlier so that the total remaining risk at any future point is minimized.

The sequencing of buildings by risk is the focus of the work of CSIRO's Data61 business unit for/with CSV, and the subject of this report. *Data61's role with CSV is not about generating knowledge about what is more or less safe with respect to building façade cladding systems. Rather, Data61's role is to capture and organise others' knowledge and provision to CSV a suitable method for applying this existing knowledge to the task of sequencing buildings according to the risk of combustible cladding façade fire. The sequencing of buildings by decreasing risk is in scope for Data61's work, however the selection of treatments to fund (if any) is not in Data61's scope.* Decisions about which treatments to apply can follow from building sequences-by-risk. These decisions will be subject to various resource constraints including the overall funding budget, and are a matter for CSV, the building industry and other stakeholders to resolve.

## 1.1 Preceding work

The Victorian Government began to address the combustible cladding problem in earnest about five years ago. Activity included building regulatory changes that curtailed the use of dangerous EPS and ACP cladding systems, the commissioning of testing of cladding panels for flammability, establishing panels of experts to advise on assessing risk and developing solutions, the identification by municipal authorities of buildings with combustible cladding risk, and the development and application of what is known as the *Risk Assessment Tool* (RAT) for capturing relevant measures of buildings' external cladding systems and the buildings' fire spread and evacuation hazards. The RAT is used by what is known as the *Advisory Reference Panel* (ARP) as part of their assessment of a building. The ARP occurs as part of the *Victorian Statewide Cladding Audit* led by the *Victorian Building Authority* (VBA). If the outcome of a RAT assessment indicates substantial combustible cladding fire risk then VBA refers the building to CSV. As such, completion of the RAT is a prerequisite for entry of a building into contention for the funding administered by CSV. RAT data is a key input into the selection and sequencing processes that are the focus of this report.

Building fires are complex phenomena. In contrast to bushfires in the landscape, there are not simulation tools that can be readily and reliably applied to estimate the outcome(s) of fire ignition events in/on buildings and their façades. Fire propagation over façades and inside buildings is dependent on numerous factors relating to materials, architecture and building systems. Many of these factors are difficult to measure and/or to source data in relation to. Even in the ideal case of a fully and accurately specified building (in its as-built and occupied condition) the simulation of the progression of fire remains a difficult scientific challenge. The outcomes of a fire are of course also dependent on the location of an ignition, environmental conditions (wind, temperature, humidity), the function of fire suppression systems, the evacuation response of occupants, and so on. In an overall sense, unlike for bushfires, the assessment of the consequences of fire via simulation methods for a fleet of buildings (such as that being addressed by CSV) is absolutely not practical using existing fire knowledge and technologies.

Victoria leads the world in addressing the problems of EPS and ACP exterior wall cladding systems. At present (in May 2021) CSV-administered rectifications to many buildings have already been completed. The development of the risk-based prioritization method that is the subject of this report was completed in late 2020 and CSV began applying it in February 2021. By contrast, authorities in the United Kingdom were just beginning to consider funding schemes and risk prioritization in October 2020 [Inside Housing (UK), 2020]. Nevertheless the problem of combustible cladding is recognised worldwide: it has prompted various changes to building regulations and the issuance of guidance across the building sector internationally [New Zealand Government, 2020], [Scottish Government, 2020]. In the United States the National Fire Protection Agency published a guidebook for assessing the fire risk of buildings with combustible cladding in February 2018 [National Fire Protection Association (NFPA), 2018]. This advocates the measurement of building attributes of a broadly similar nature to those used in the Risk Assessment Tool in Victoria (refer Section 4), and brings these together into a rectification method selection and prioritization process which has similarities to what is proposed in this report (refer Section 5) however using weighting schemes rather than pairwise comparisons and a sequencing logic.

### 1.2 Design criteria for a risk prioritization approach

CSV engaged Data61 in September 2020 to develop a risk prioritization approach for Class 2 buildings with combustible cladding. An approach needed to be devised and be fit for application to the fleet of buildings within CSV's remit by late 2020. The business need, the timeframe, and the already advanced state of the program by the second half of 2020 gave rise to a set of logical and pragmatic design criteria for a risk prioritization approach. Some of these criteria were explicitly established *a priori* and others were emergent or implicit. Criteria (not in strict order of importance) that the risk prioritization method needed to satisfy were/are:

1. The method must be able to be applied to several hundred exising buildings in Victoria using expertise and resources that can reasonably be foreseen to be available by CSV during a period ending in early 2021.
2. The method can readily be understood and broadly supported by knowledgeable and competent practitioners ("subject matter experts", SME) in the building industry.
3. All assessments and judgements (of building fire severity and occupant egress difficulty) that are made/utilised through applying the method to buildings must be made by SME, and it must be clear to SME when they are making such assessments and judgements during the process.
4. The funding program is about reducing or eliminating the "risk premium" of a building *due to the presence of EPS and/or ACP* and the method should focus SME attention/judgement on assessment of that premium, not on broader risk/safety issues that may be associated with the building.
5. The data needed about buildings can be gathered readily using an amount of resources and effort that is considered reasonable by CSV.
6. The method is part of an opportunity/candidate screening process and is not intended to provide complete and definitive assessment of risk.
7. The method is not required to be useful for assessing the suitability of any particular risk reduction treatment(s) on any particular building(s).
8. The method can be applied by SME that are trained and competent in its application on each occasion that a candidate building enters the program.

## 2 Overview of the Cladding Risk Prioritization Method (CRPM)

Classically, risk is *expected loss* and in the case of events that may happen once or more over time this becomes either the *long-run average loss per unit time* or some other long-run metric over a loss per unit time probability function (such as the 95th percentile). In this sense we require *event likelihood* and *event consequence* information, and quantifying risk involves estimating these values and then multiplying them together and summing the result over the set of possible events (in cases where we are dealing with a finite set of events). In the context of residential buildings we would have great difficulty in quantifying likelihood (as rates of occurrence) and consequence (in holistic units of loss such as money or life-years):

1. Enumeration of prospective ignition points on/in a building is a laborious manual process and does not scale over a program of hundreds of buildings. AI-based approaches in theory may be applicable in this regard but would require many person months or years to design, develop and validate to a sufficient standard.
2. Some observational data is available about fire ignition rates at different characteristic locations (e.g., kitchens or balconies). Practitioners with knowledge of building fire have intuitive understandings of relative likelihoods of ignitions. This data and knowledge is not sufficient however for reliably and repeatably evaluating with some quantitative accuracy the likelihoods of ignition events at various potential ignition locations for specific buildings.

3. Estimating the consequence of an ignition, or moreover of numerous potential ignition points over every specific building of interest, is not practical. This is because of shortcomings in data availability, software, and in relevant science.

In the combustible cladding context the minimization of expected loss is not necessarily the foremost aim of the Victorian Government and CSV. Reeling in the maximum foreseeable loss, to avoid a major catastrophe, is closer to the true intentions. For all of the aforementioned reasons, we seek a risk prioritization approach which:

1. Focuses on the ignition points on/in buildings which could lead to the largest of combustible cladding fires on the façade these buildings.
2. Collapses the domain of likelihood into a binary choice of $\{implausible, plausible\}$ and therefore considers all of the plausible ignition points for cladding on a building façade as being broadly equivalent from a likelihood perspective.
3. Simplifies consideration of the process of fire escalation from an ignition to a façade fire, to one where the (likelihood of) escalation is assessed as being a $\{implausible, plausible\}$ binary choice, and that escalation is only considered $implausible$ in cases where sprinkler systems such as "drenchers" are essentially guaranteed to extinguish an ignition.
4. Estimates the consequence of an ignition according to simplified measures which can be assessed in a reliable and repeatable way by building fire practitioners, which for this work becomes a measure of the maximum foreseeable extent of combustible cladding consumption in a façade fire from a $plausible$ ignition and fire escalation point on each given building.

To elaborate on the last of these points, the (worst case) consequence of an ignition was estimated by an SME panel in terms of **the maximum number of Single Occupancy Units (SOU) that could be involved in a façade fire**; or in short, the **maximum SOU**[1].

## 2.1 Maximum SOU and building occupancy

The maximum SOU measure is an integer quantity that will range from zero to the number of SOU contained in a building. It is the maximum (worst-case) number of SOU that would be directly impacted by fire on/in an interconnected section of combustible cladding, for the worst-case (highest SOU count) plausible locations on the building façade where fire could engage combustible cladding and be propagated principally by the cladding.

- A fire does not need to be initiated at the plausible worst-case location. It might for example begin in an internal kitchen and spread to the cladding by way of a "flashover" (flame or heat transfer) through a window opening.
- An interconnected section of combustible cladding does not need all surfaces/panels to be physically connected (adjacent). Rather, each surface/panel needs to be sufficiently proximal to others to enable fire to carry between them by flame, radiant heat or the burning of other façade materials.
- Although it is entirely conceivable that a fire event on a building may result in the consumption of two non-interconnected sections of combustible cladding by fire because of fire propagation through the interior of the building, the maximum SOU measure does not add the SOU of these sections together, but instead is the SOU count of the maximum section.
- It is only possible for a building's maximum SOU to equal the number of SOU in that building if: (i) all SOU have external walls; (ii) every SOU has combustible cladding on one or more of these walls; (iii) one interconnected section of combustible cladding can span every SOU.
- It is only possible for a building's maximum SOU to equal zero if no SOU has combustible cladding on one or more of its external walls.

SOU across the relevant building stock in Victoria range in size: from those SOU which can only comfortably accommodate a single person, to SOU that might comfortably accommodate a large family. Depending on diurnal patterns, the dynamics of the property market and the styles of living followed by occupants we may also observe different expected numbers of people present in an SOU and building at different times of day, months of the year, and future years. Age, ability, ethnicity or other differences between the occupants of different buildings can mean that the expected number of injuries or fatalities per SOU might vary. Despite all of this inferring that the number of people potentially exposed to fire hazard in each SOU could vary markedly with time and with SOU size, we do not

[1] An SOU is a well understood concept in the building industry, and in more common language is synonymous with the *number of apartments* in a multi-tenancy residential building

normalize maximum-SOU to account for any of these factors. In an overall sense, our prioritization method treats all buildings and SOU equally in these factors. SME and rectification program managers are encouraged to "promote" or "demote" buildings in priority-ordered lists to account for these factors as exceptional cases.

## 2.2 Phases of the CRPM

The CRPM consists of a *design phase*, a *cohort prioritization by attributes phase* (or more simply put, a *cohort sequencing phase*), and an ongoing *building assessment phase*.

- A panel of SME could execute the approach linearly, i.e., step-by-step. In actual practice with CSV the phases overlapped in time and parts of different phases were executed iteratively. The details of this overlap and of the process iterations would add unnecessary complexity to this overview, and are omitted. The method is most readily understood in overview by considering it as a linear process.
- In 2020 the progression through the phases was done with intensive participation by the Data61 staff (i.e., the first two people listed as authors of this report) as well as CSV non-SME staff. This input is not strictly required for future revisions nor for the application of the methods in other jurisdictions in future.

Information about a set of approximately 350 buildings in Victoria with combustible cladding was available to the team (of Data61, CSV and SME members) as a reference throughout the period that the method was being developed. The SME had detailed prior knowledge of many of these buildings, e.g., through having carried out site visits and assessments at times prior. These buildings were also to be subject to CSV's application of the risk prioritization method once the method was developed; i.e., they were the set of buildings that had entered CSV's program and which had not yet been declared as sufficiently safe, out of scope (e.g,. not high enough, or not Class 2 Residential), or of such high risk that cladding removal had already been committed to.

**In the design phase**, a panel of SME decide which attributes of buildings will be utilised for combustible cladding risk prioritization purposes.

- The set of selected attributes should be small in number, say, of cardinality of about ten or less.
- An attribute value applies to a building in its totality, i.e., an attribute does not take a certain value in one part of the building and another value in another part. For some attributes this can mean that its definition is a worst-case or maximum over a building.
- Each attribute is relevant in the consideration of the building's risk premium due to combustible cladding.
- Each attribute is measured on an ordinal scale, whether numeric or categorical.
- It needs to be practical to assign attribute values to buildings using existing data or by applying a moderate amount of effort in new data gathering, synthesis and/or analysis.

The SME also classify the permitted values for most attributes into classes of higher or lower contribution to combustible cladding fire hazard severity. This effectively reduces the attribute's domain to "low" and "high". The underlying logic and mathematics of the method require that attribute values are ordinal, but it is not required that all or even any of the attributes actually have their domains reduced to such a binary state. From a practical perspective the second phase of the method is more straightforward to apply when the attributes take binary values. The reduction of multi-valued domains into binary domains does naturally mean that information is simplified and some detail is "lost". When considering the variables, measurement scales and the available data, the information loss is not a severe issue and is counterbalanced by increases in the repeatability and consistency of SME judgements which are afforded by a simpler binary-based measurement system.

In this phase the SME also decide on a partitioning of the candidate buildings into *groups* within which comparisons are considered more valid and more robust (i.e., we do not wish to compare large high-rise CBD buildings to lower-rise suburban apartment complexes). This partitioning is defined using a selected subset of the attributes. In effect we are dividing the set of selected attributes into those which are group-defining and those which are not.

**In the cohort sequencing phase** the SME consider combinations of the non-group-defining attributes within each group. These combinations define building *cohorts* within the groups. The combinations of relevance actually emerge largely from assigning attribute values to the set of reference buildings (partitioned into groups) and then recording the distinct combinations that appear. The opportunity also exists to include those combinations of attributes which might be expected to be observed in new cohorts in future.

The SME panel have the task of sequencing cohorts within each group by their perception of the combustible cladding fire hazard severity. The sequence progresses from highest perceived hazard in total to lowest perceived hazard in total. Buildings within a cohort are assumed to present roughly equivalent hazard even though they may exhibit major design and situational differences. How the panel carry out this sequencing in an effective, repeatable and logically-consistent manner is a major aspect of the method design. We delve into the details of this in subsequent sections. Verification ("stress testing") of the findings, including testing the logical consistency of the SME panel's decisions using graphical representations, occurs at the end of this phase, along with information consolidation about the cohort sequencing so as to prepare for the final phase.

To be clear, it is not a requirement of the method that the set of buildings is actually known during this phase. It is mainly a matter of efficiency and convenience that a reference set of buildings is available. The use of a reference set of buildings enables unlikely attribute combinations to be ignored; possibly to be added-in later if they materialize in practice. The effort asked of the SME panel is reduced when only the observed and likely attribute combinations are considered. A further benefit of having a reference set of buildings is that one or more buildings can be taken as exemplars of each cohort[2].

Reference to these example buildings can facilitate informed decision making about sequencing. They also can trigger a return to the design phase if it becomes apparent to the SME panel that the buildings within a cohort exhibit too much variation — noting that this is a potential outcome and that it did not occur in practice.

**In the building assessment phase** each building is assessed so as to associate it with a full set of attribute values (as selected in the design phase) and hence to assign it to a group and a cohort. When all candidate buildings have had their group and cohort membership established a priority order of buildings is implied by the cohort sequence that is determined in the cohort sequencing phase. This leaves open for further consideration three prioritization questions:

1. What the intra-cohort priority order might be. If there is an order of buildings within a cohort then this will result from the case-by-case consideration of buildings by rectification program managers and SME. The criteria and processes used for this are not in scope here. This is not a particularly important question because under most circumstances if one building in a cohort is selected for a risk reduction treatment then all buildings in a cohort will be.
2. Whether there are special cases where buildings should be promoted-above or demoted-below their cohort position in the sequence. This again will result from the case-by-case consideration of buildings by rectification program managers and SME. How this is done is also outside of the scope of this report; however, it is very important that this task is carried out thoroughly. There are buildings with pertinent exceptional aspects such as being situated in very close proximity to neighbouring structures, having elevated community value, or posing severe logistical issues for cladding rectification work.
3. How the ranked lists of buildings for the different groups might interleave. This question is important for CSV's rectification program management. The groups define sets of buildings which in informal terms are "apples and oranges" and difficult to compare in the basis of façade fire risk. Under a budget constraint for example, CSV's rectification program management team must make the "apples and oranges" trade-off but we do not seek to resolve this "optimisation" question here.

## 2.3 The CRPM in detail and in practice

Much of the remainder of this document expands on this overview, describing the CRPM, the tools that were developed and used, the motivations and science supporting the CRPM development, and information about the CRPM application in practice. Before embarking on this we highlight two important aspects of the CRPM's application by the team of SMEs that have been engaged by CSV:

- In practice the building assessment phase largely *preceded* the cohort sequencing phase. The relative sequence of these two phases is essentially unimportant. Because the building stock to which to apply the prioritization method was known from the outset it was convenient to assess this stock before cohort sequencing. The building assessment phase was much more time consuming (involving about 120 person-hours of effort by SME) than any other part of the CRPM process. The assessment process helps to refine the SME's understanding of the building stock, façade fire considerations, and the prioritization method itself.
- The assessment of buildings for cladding risk and rectification has of course taken several years of effort by a team of people (led by the VBA before CSV came into existence). The building assessment phase of the method involved some amount of data processing by CSV and Data61 to organise the results of this past effort. Most of the effort in the building assessment phase involved SME estimating the consequences of a façade fire for each building in terms of "maximum SOU" as outlined earlier in this section.

[2] In practice, the CSV non-SME and Data61 team gathered information into a database and then created an automated document generator which output a HTML document providing summary data and imagery for every reference building arranged by group and cohort

# 3 Building stock

CSV's rectification program deals with Class 2 residential buildings[3] with combustible cladding and which satisfy certain building height, ownership and risk thresholds. Many but not all of the buildings are located in suburban Melbourne. The map in Figure 3.1 covers the buildings with combustible cladding that appeared in CSV datasets in October 2020. A few dozen additional buildings entered the program since that time and up until May 2021. Additional buildings might continue to be nominated in future. The list of buildings that are within CSV's scope is not publicly released by the Victorian Government and is considered to be sensitive information.

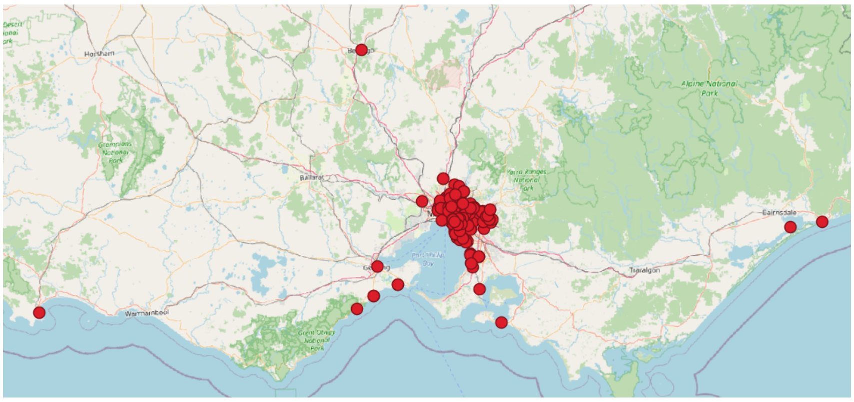


Figure 3.1: Locations of buildings with combustible cladding (473 addresses, 468 distinct locations)

In Metropolitan Melbourne most buildings with combustible cladding are in the north, east and south-east (Figure 3.2). In the southern bayside area, all of the (nominated to CSV, residential class 2) buildings with combustible cladding are in a cluster between Bonbeach and Frankston South (Figure 3.3).

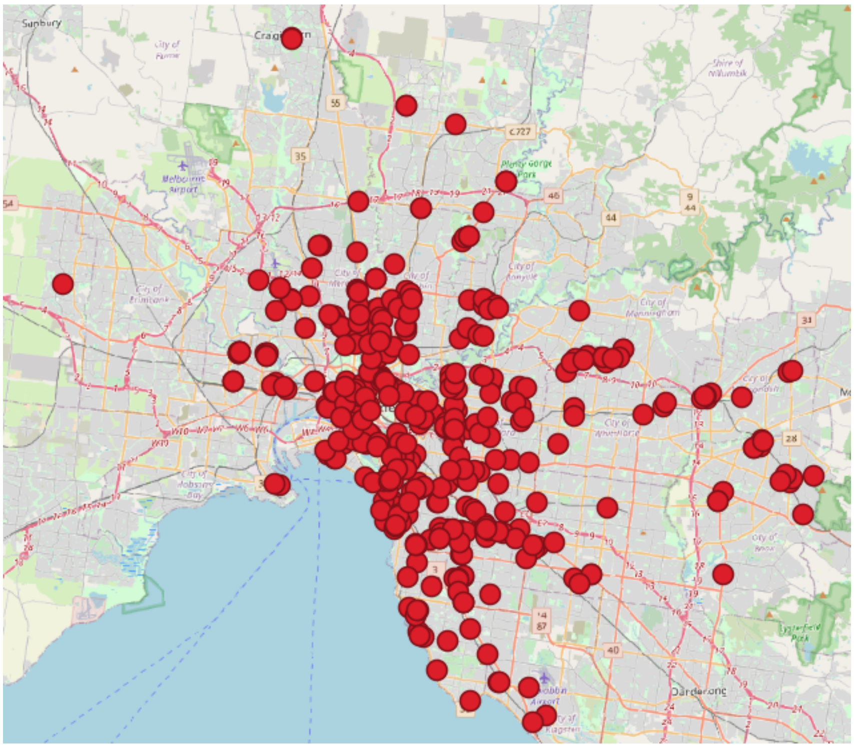


Figure 3.2: Locations of buildings with combustible cladding - Melbourne Metro north of Bonbeach

[3] Refer https://www.vba.vic.gov.au/building/regulatory-framework/building-classes for an overview of building classes in Victoria

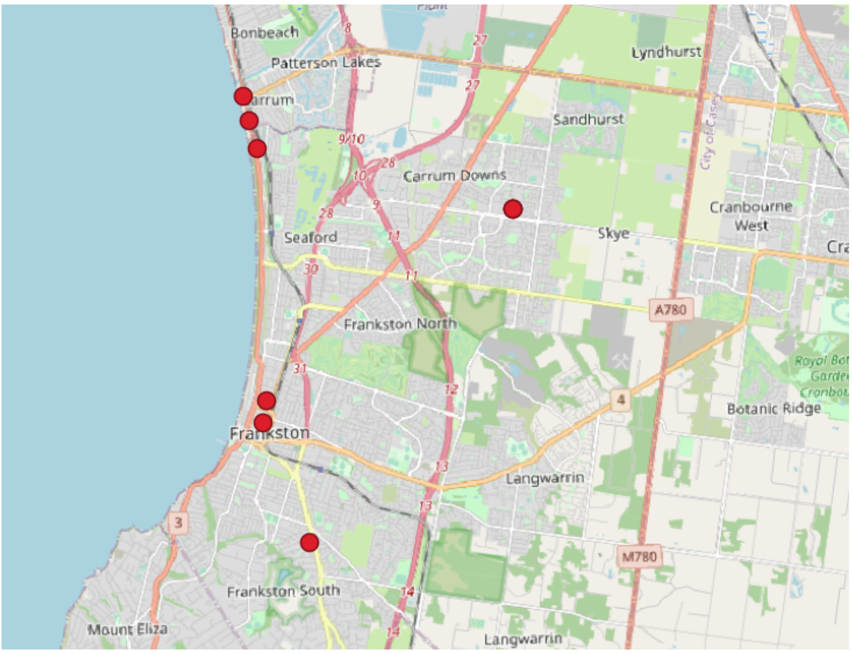



Figure 3.3: Locations of buildings with combustible cladding - in the proximity of Frankston

A few buildings have an exposure to the effects of vegetation fires (i.e., grassfires and bushfires), including buildings in Bundoora, Plenty Gorge and Anglesea. The threat from vegetation fires was considered early in Data61's work (refer Appendix D). With reference to the set of in-scope buildings, in building experts' view the vegetation risk threat was a special-case issue and was left for case-by-case program management intervention rather than be assessed within the mainstream prioritization method.

Class 2 residential buildings range from two storeys in height and a few SOU to inner-city buildings with dozens of floors and hundreds of SOU. A selection of images of buildings that have been referred to CSV's cladding rectification program is shown in Figure 3.4. ACP combustible cladding is particularly prominent in these, including but by no means limited to the colourful architectural elements of the façades and many of the silver, cream, brown, black and mid-grey surfaces.

Figure 3.4: A selection of Melbourne metropolitan Residential Class 2 buildings with combustible cladding (all images copyright Google)

## 4 The Risk Assessment Tool (RAT)

By October 2018 the Victorian Building Authority by way of its Advisory Reference Panel(s) (ARP) had completed its initial assessment of 1369 buildings and planning permits where (potentially combustible) cladding had been specified as a construction material [Victorian Cladding Taskforce, 2018]. The finding of these assessments were captured for each building by a building risk screening and assessment instrument known as the *Risk Assessment Tool* (RAT). The RAT was designed by the Victorian Cladding Taskforce members and has been through many iterations, the current one being Version 12.

In the field the RAT consists of a set of questions supplemented by guidance on terminology, meanings, protocols and measurement scales (refer Appendix E). The data collected from the application of the RAT can be assembled into a tabular dataset with one row per building and a number of data fields as columns. Depending on the RAT version there are around 18 columns of data. Most data fields have values in categorical ranges consisting of four or fewer permissible values. For example, the number of SOU in a building is expressed as one of four discrete ranges of: up to 10 SOU; 11 to 50 SOU; 51 to 150 SOU; or more than 150 SOU.

Once a building has been assessed by the ARP using the RAT then if the outcome of the assessment indicates that the risk is considerable then under current processes the building is referred to CSV. CSV then oversees a "due diligence" process involving inspectors and engineers. Expert panels meet regularly and iteratively consider the findings of building assessments, with their deliberations leading to further investigations and ultimately to either cladding removal and replacement works being undertaken or a building being excluded from the program. The RAT is in essence used to screen buildings for this more intense investigation period. CSV use a scoring system (implemented as spreadsheet formulae) for judging whether the risk is sufficiently substantial to warrant further assessment beyond the RAT. In this scoting system:

- The majority of RAT data variables are assigned to either a set of *fire risk* variables or a set of *escape risk* variables.
- The categorical levels of each RAT variable are mapped to score values, with the higher values representing greater perceived risks.
- A weighted sum of the RAT variable scores is computed for fire risk and egress risk, and then each is discretized to an ordinal categorical value.
- The combination of fire risk and escape risk categorical scores are each mapped to one of four classes of risk for buildings with some amount of combustible cladding.
- Buildings in the maximum category for risk are considered to be of "extreme" cladding fire risk and many of these were already being rectified using Victorian Government (CSV) funds by mid-to-late 2020.
- Buildings in the middle category for risk are "high" risk and in scope for risk prioritization using the methods that have been developed by Data61 and are described in this report.
- Buildings in the lower categories for risk, or which are ineligible for cladding rectification funding under CSV's program, are de-prioritized or rejected/released from the program.

In this sense, the RAT uses a conventional risk matrix with fire risk and escape risk axes, to put buildings with combustible cladding into four classes of risk: "low", "moderate", "high" and "extreme". The risk prioritization method developed by Data61 is applied to the "high" risk category in which there were approximately 350 buildings in early 2021. Figure 4.1 shows the RAT dataset from around October 2020. In this, most "moderate" buildings have been removed from the dataset prior to it being delivered to CSIRO, and most of the remaining buildings are rated "high" risk.

The RAT considers the buildings largely in isolation. Other than the transmission of fire from one building to the next, there is no scoring of external threat. External threats we speculate will include:

- Bushfire, grassfire and urban vegetation fire;
- Vehicle impact and vehicle-initiated fire due to road traffic and public parking;
- Rubbish bins, storage areas and other places where fuels can accumulate and be ignited by chance, vandalism or carelessness;
- Public places with elevated levels of activity and gathering, including laneways and secluded areas where people might loiter (e.g., official or unofficial smoking areas);
- Restaurants and other commercial activities which might pose heightened ignition risk.

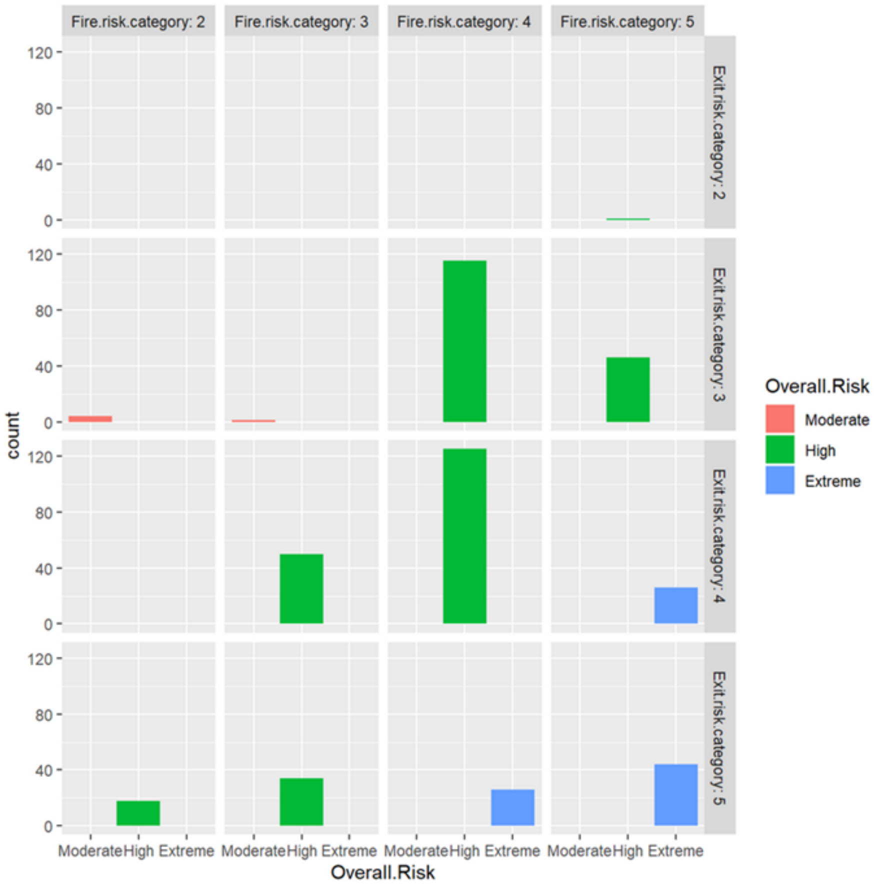



Figure 4.1: RAT buildings data by fire risk, escape risk, and overall risk category

In general the consideration of these threats is associated with judging fire likelihood rather than fire consequence or fire possibility. For example, a potential and estimated rate of vehicle strike does not make the ignition of a fire at a certain point on the building *possible*, rather it makes the possible more *likely*. This is because a fire at the same point could almost always be achieved through various other means including deliberate acts of arson.

The eventual direction of the risk prioritization for CSV was one where likelihood was not assessed. The focus instead was on fire possibility and fire maximum possible loss. Therefore external threat assessment did not become part of the CRPM method for prioritizing buildings by combustible cladding risk.

## 4.1 RAT variables

We can classify the RAT variables by what they are primarily intended to indicate (here we concentrate on variables that are common to Versions 11 and 12 and which are the most relevant). In the following the variable names are fairly self-explanatory; further detail is given elsewhere in this document including in Appendix E.

- Building size factors
  - `Number.of.occupants...sole.occupancy.units`
  - `Number.of.storeys`
- Building structure factors
  - `Types.of.cladding.present`
  - `Extent.of.combustible.cladding`
  - `Configuration.of.cladding`
  - `Fire.rating.of.external.walls..behind.cladding.`
  - `Windows..doors..or.other.openings.adjacent.to.cladding`

  - `Insulation.type.behind.cladding`
  - `Fixing.method`
- Escape factors
  - `Egress.provisions`
  - `Speed.of.Evacuation`
- Fire likelihood modifying factors
  - `Proximity.of.cladding.to.potential.ignition.sources`
  - `Risk.of.cladding.fire.to.or.from.adjacent.buildings`
- Fire escalation modifying factors
  - `Automatic.suppression..sprinklers`
  - `Fire.fighting.provisions`

Refer Appendix E for some detail on variables' permissible values and assessment guidance.

All RAT data is *complete* for each building but the *quality* of the data collected by the RAT does vary. There are variables including `Egress.provisions` which SMEs state can be assessed differently by different assessors/inspectors. Some variables show low discrimination of values, with middle parts of a range of values being largely unused. Other variables including `Insulation.type.behind.cladding` are very difficult to assess in the field and can either represent educated guesses or risk-averse default values depending on assessors'/inspectors' leanings. Where relevant we touch on these issues further in this report including in Section 5.6.3.

One of the key RAT variables is `Types.of.cladding.present`. The RAT defines four cladding types, which generally represent increasing levels of risk:

| Level | Score | Description |
|---|---|---|
| 1 | 0.25 | $\leq 10\%$ PE content ACP |
| 2 | 0.5 | $\leq 30\%$ PE content ACP |
| 3 | 1 | Expanded polystyrene or ACP PE or ACP unclear |

Table 4.1: Cladding types, in increasing order of risk

PE in this context refers to Polyethylene. The PE content of ACP is indicative of the amount of energy released on combustion, the thermal barrier to combustion, and/or the rapidity of combustion (the relationships are not linear and vary between specific core compositions and manufacturers). EPS cladding, being expanded polystrene board, does not have a metal facing in some products/applications. ACP is a sandwich of two thin aluminium sheets which are bonded to a polymer core. In ACP it is the polymer core that makes this product combustible, but once sufficient fire temperatures are reached the Aluminium does become engaged in the fire. There are multiple types of ACP with greater and lesser fire hazard. A two page flyer on ACP has been issued by VBA (refer Appendix **??**) which covers some of the basics. ACP with less than 10% PE content is considered fire rated, and does not need to be removed from buildings. "QT" cladding (https://www.qt-sys.com.au/) may be considered fire rated and also might be considered sufficiently safe. ACP with more than 10% PE but 30% PE or less is in scope for rectification but presents less risk. (*Some of the asessments and thresholds referred to above have evolved in VBA and CSV over the course of 2020 and 2021 and what is written here is indicative only.*)

# 5 The Cladding Risk Prioritization Method (CRPM)

In this section we describe the motivations and design for a *Cladding Risk Prioritization Method* (CRPM). The unavailability of an automated means to assess fire likelihoods for a building and fire outcomes for a building leads us naturally to harness human expertise instead. In the CRPM this expertise will be applied to the estimation of fire outcomes as well as to estimation of how multiple factors interact to enhance or alleviate the risk of fatality or injury. Human expertise and intuition has advantages in being able to deal with complexity and generate insight based on limited information, and disadvantages around repeatability, accuracy, precision and the volume of assessments/computations that can be asked of individuals and groups within a reasonable amount of time. In undertaking estimations and rankings humans are better at making relative judgements (e.g., comparing pairs of buildings successively) compared to absolute judgements (e.g., rating of buildings one-by-one on multi-dimensional scales). We begin this section by outlining the principles by which we will harness expert knowledge and insight in the CRPM, including drawing on some of the relevant literature.

## 5.1 Human expertise and risk assessment

Quantitative risk assessment and modelling requires data on the frequency of initiator events as well as conditional event probabilities. Because empirical data is often not readily available or difficult to obtain through other means, expert judgement has been found to be a valuable method and source of information [Rosqvist and Tuominen, 1999]. Expert judgement is useful when other measurements, observations or data sources are unavailable or can be used to supplement existing sparse or questionable data [Meyer and Booker, 1990]. Criticism of expert judgement methods focus on issues such as potential expert bias, or that judgements can demonstrate high variability across the experts which would prohibit accurate estimations. Therefore, a clear method has to be established to achieve consensus amongst experts [Cooke and Goossens, 2008].

Research shows that people are better in making relative judgements, such as pairwise comparisons, rather than direct estimates [Meyer and Booker, 1990]. Meyer and Booker argue that most people are reliable estimators using pairwise comparisons. Such comparisons are well within the limits of information processing capabilities as only two alternatives have to be considered at a time. Furthermore, after brief introduction to the method, people usually find such comparisons an easy method to use. Yet, the method can be time consuming if all possible combinations of pairwise comparisons have to be elicited and it only provides relative data relations. Other evidence for the value of relative judgements also comes from research on eyewitness identification of crime suspects. For example, results from Moreland and Clark [2020] suggest that "side-by-side comparisons increase diagnostic accuracy by allowing witnesses to give greater weight to more diagnostic features and less weight to less diagnostic features". Goffin and Olson [2011] provide social cognitive as well as evolutionary explanations for why people make more accurate ratings using comparative measures ratings as compared to absolute ratings.

In our CRPM method for buildings with combustible cladding we strongly emphasize the assessment of relative risk, and are in keeping with the findings in the literature above:

- We directly exploit the relative reliability of comparisons between a small number of options (i.e., a few buildings), in line with the observations in Meyer and Booker [1990] about pairwise comparisons, and also in alignment with well-established behavioural economics principles around humans performing better when faced with only a few discrete choices (e.g., see Reeson and Dunstall [2009]).
- We use computational logic (i.e., logic exercised by computers) to "lock in" incontrovertable prioritization facts. For example, "all else being equal", a building with more highly combustible cladding poses more risk than one with less combustible cladding. Simple rules of this kind can be encoded and then exercised by software systems that support the expert knowledge elicitation processes. Complex logical deductions can be made by applying a network of simple rules.
- We reduce the number of comparisons that are needed by way of defining *cohorts* of different buildings that exhibit the same summary-level risk profiles. Comparisons are made between example buildings from cohorts.
- We do not require all possible comparisons to be examined between cohorts, rather, we only seek experts' views on pairwise comparisons that cannot be resolved in software by logic.
- We present comparisons to experts in a sequence which has a mutually-understood structure, namely, that experts are almost always choosing the next most important cohort of buildings from amongst a small candidate set of cohorts.
- The CRPM building cohort comparisons process is in fact quite similar to *critical path methods* for project management, which given the building domain subject matter, was of some benefit in helping experts under-

stand the underlying logic of the approach.

- The population of buildings is broken into groups which are more homogenous (e.g., tall buildings with automatic sprinkler systems) so that building cohort comparisons are more “apples to apples”.

The use of various types of multi-criteria weighting schemes is popular for decision-making. It has been applied by NFPA in their approach to combustible cladding [National Fire Protection Association (NFPA), 2018] and was applied for risk classification by VBA within the RAT (Section 4). Weighting of criteria can enable many criteria to be considered at the outset. Criteria weighting schemes can be used to progressively collapse this complexity down into a smaller-dimensional space. For cladding risk assessment with the CRPM we do not utilise multi-criteria weighting nor the related methodologies such as AHP.

It is the authors’ view that weighting schemes are flawed approaches for risk assessment because experts’ choices of weight are almost always corrupted by their expectations of the outcomes of applying those weights, and in turn by their own “utility functions” as individuals. As such, methods based on weighting schemes while attempting to capture experts’ rationality and expertise can equally reflect their beliefs, biases, pre-conceived expectations and so on. The beliefs and biases can be expected in many cases to be well-founded and synonymous with well-tuned intuition. Nevertheless, in our view a more robust and unbiased result is obtained by harnessing experts’ strengths in undertaking comparisons and rankings in the ways described above. Our negativity around weighting schemes is compounded in the case of combustible cladding because of the contentious nature of the topic and hence the almost guaranteed emergence of largely unresolvable arguments *with domain experts outside of our own expert panel* about the correctness of weight values. Overall we require CRPM to be a method with very few parameters (i.e., without weights) and with as much irrefutable rule-based logic as possible.

## 5.2 The CRPM in summary

The method enables buildings to be sequentially ranked based on risk attributes which in the main are derived from the RAT. Buildings are characterised by a set of measurements/estimates for the values of each of several *risk factors* such as “firefighting provisions” or “type of cladding”. Most of these values are discretized to a zero-one value (i.e., low or high relative risk) and this often results in several buildings sharing the same values across all factors and therefore forming a *cohort*. The ranking process uses priority rules for building cohorts which are expressed in terms of the risk factor measures. The priority rules stem from the application of logic and from information on comparative building risk that is elicited from domain experts (i.e., our expert panel). The information on comparative building risk is obtained by using buildings in CSV’s program as examples, but the sequential ranking is generated without direct human input: the priority rules are sufficient for developing a ranked list. These rules do not need to be revised each time a ranked list is formed or updated; they only need to be revisited when new buildings enter the program and are different.

Figure 5.1 is one view of the CRPM and its application. This complements the three-phases view that was provided in Section 2.2. The box top-left in Figure 5.1 is the core of the **design phase** and we discuss this beginning in Section 5.3 principally in Section 5.6. The remainder of the left-hand column of Figure 5.1 constitutes the **cohort sequencing phase**. The fundamentals of the cohort sequencing phase are discussed in Section 5.5. The **building assessment phase** is represented by the activities in the right-hand column of Figure 5.1. In this phase the buildings are associated with values for the RAT and other variables that (due to the decisions made during the design phase) are used to define cohorts of buildings. The cohorts are formed and the sequencing logic is applied to these cohorts.

## 5.3 The RAT as a foundation for the CRPM

Our pragmatic decision is to build upon the existing data and ratings of the RAT. In doing this we recognise that the RAT is not a perfect foundation, especially for measurements/variables are considered to have low repeatability or discrimination. With reference to Table 5.1, specific examples of this are:

- The RAT variable `Windows.doors.or.other.openings.adjacent.to.cladding` has weak discriminatory power because almost every building has windows/doors with adjacency to cladding.
- The RAT variable `Fire.rating.of.external.walls` also has weak discriminatory power in practice because most buildings are assessed as not meeting fire rating requirements. We further understand that buildings for which the fire rating was difficult to determine were rated as not meeting requirements, and that satisfaction of fire rating requirements in much of an external wall would not counteract other sections’ unfavourable rating. The situation is very similar with respect to `Insulation.type` where uncertainty about the insulation type is far more common than not, and is reflected in unfavourable default ratings.

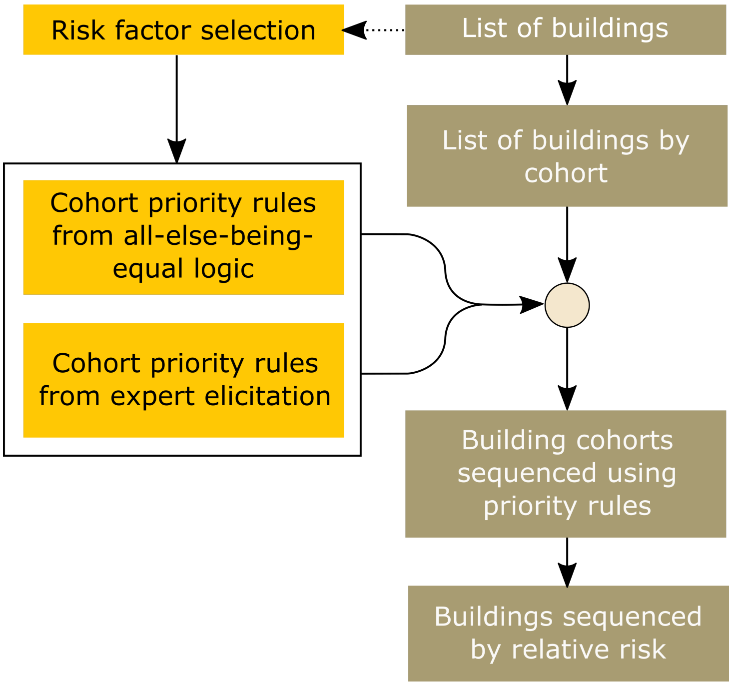



Figure 5.1: Building priority ranking workflow

- Frequently the SME panel as well as other individuals involved in consultation during the latter parts of the project observed that egress and/or firefighting provisions assessments could result in unfavourable ratings because of technical deficiencies in an otherwise relatively sound approach in a building, and/or to the outlook and priorities of particular assessors.
- The more straightforward variables such as `Number.of.occupants.` and `Automatic.suppression..sprinklers` are not prone to unfavourable ratings that might otherwise be due to uncertainties or to an influence of subjectivity.

The RAT does not have variables which directly indicate the likelihood of fire ignition, the likelihood of fire of different extents, nor how the measured factors might combine to produce of fire of greater or lesser consequence. Therefore a RAT-based approach cannot be used for assessing expected loss over time and the quantification of risk. Conversely, it is impractical and unnecessary to cast the RAT aside and assess buildings afresh. Our approach must pragmatically concentrate on risk relativities and on more readily estimated *maximum foreseeable loss* measures.

## 5.4 Risk reduction objectives

The risk objective for CSV is associated with the principle that avoidance of fatalities and injuries is paramount. In the method as ultimately formulated this is not only the primary concern, it is the only concern that influences building priority.

If we were to extend our concerns beyond this, then secondary objectives would be the minimisation of: (a) direct economic loss associated with the building; (b) damage to surrounds; and (c) disruption to normal activity (transport, employment) during investigation, cleanup, demolition and rebuild. All of these will be somewhat proportional to the number of SOU impacted, but of course is also dependent on other factors. Tertiary objectives might include loss of social amenity; loss of important social function eg disability housing; loss of land value, economic activity and local market for goods/services; damage to civic pride, political implications, loss of community confidence in Government, and so on.

We are interested in risk retirement sequence but do recognise that in practice the sequence might have as much to do with the speed at which building owners corporations choose to move as it does CSV imparting priorities. Nevertheless retirement of as much risk as early as possible is at least an aspirational objective for CSV and as such we seek to form sequences of buildings by decreasing risk.

Given the above we will be viewing risk solely in terms of threat to life. The prioritization method should seek to ensure that if not all buildings are fully rectified then those that are rectified are those with higher threat to life. We

| VARIABLE NAME | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| Number of occupants or SOU | 46 | 171 | 40 | 30 |
| Types of cladding present | 9 | 278 | | |
| Extent of combustible cladding | 164 | 71 | 52 | |
| Configuration of cladding | 12 | 14 | 49 | 212 |
| Fire rating of external walls behind cladding | 42 | 245 | | |
| Windows, doors or other openings adjacent to cladding | 1 | 286 | | |
| Insulation type behind cladding | 33 | 5 | 249 | |
| Fixing method | 142 | 145 | | |
| Egress provisions | 2 | 86 | 165 | 34 |
| Speed of evacuation | 5 | 158 | 117 | 7 |
| Proximity of cladding to potential ignition sources | 1 | 30 | 142 | 114 |
| Risk of cladding fire to or from adjacent buildings | 18 | 49 | 105 | 115 |
| Automatic suppression (sprinklers) | 10 | 129 | 48 | 100 |
| Fire fighting provisions | 1 | 68 | 166 | 52 |

Table 5.1: RAT variables, counts per level (as at December 2020). The numbers 0 to 3 represent the levels with increasing risk. As the variables have between two and four levels, the lowest level was set to 0 and any unused levels left blank.

should also seek a sequence of buildings by non-increasing risk so that the potential exists to inform the earlier retirement of higher risk buildings.

## 5.5 Focus on equivalence and difference between buildings

The RAT provides us with a set of variables which are all able to be viewed as *inputs* to the estimation of fire outcomes for a building. We require expert judgement to connect these inputs to fire occurrence *outputs*. We do not have computational models for doing this. Estimation based on human expertise is difficult challenge for experts: we are asking "how do cladding types, insulation, wall fire rating compliance, egress and firefighting provisions combine?" We refrain from posing this challenge to experts in a way that would require them to weigh the multiple dimensions simultaneously and/or envisage a magnitude of fire outcome. Rather we focus as much as possible on simpler questions for which the answers are more robust and the logic is incontrovertible. Specifically, we seek to reduce the complexity of building fire risk into a system of facts which when acting together are largely sufficient for resolving building ranking. The majority of these facts come from logical deduction and the remainder come from expert judgement.

Figure 5.2 contains images of two buildings that are amongst the population of buildings in the cladding rectification program. These two buildings are rated equally according to the RAT except in terms of the number of apartments and height, the building on the left clearly being larger and therefore of no less risk than the smaller building on the right. By a straightforward "all else being equal" principle, it is not logical for the building on the left to be ranked lower in a risk priority list than the building on the right.


Figure 5.2: Buildings with combustible cladding that differ principally in the number of apartments and height

Similarly, in Figure 5.3 there are two buildings are rated identically according to most variables in the RAT except for egress provisions, where the rating is "poor" for the building on the left and "good" for the building on the right. Again by applying an "all else being equal" principle, the building on the left should be ranked higher than the building on the right in a risk priority list.

Figure 5.3: Buildings with combustible cladding that differ principally in the RAT egress provisions rating

Consider the scenario where building risk will be measured by just three factors (storeys, cladding extent and egress) and that the measurements for each of these factors are simplified into a value of either zero (lower risk) or one (higher risk). The measurement can be written as a vector $[x, y, z]$ of zero-one values for the three factors respectively. The four buildings of the preceding two figures (Figures 5.2 and 5.3) and their RAT assessments then form a *network* of facts where one building is logically most risk, three buildings (right hand side) form a clear sequence of decreasing risk, and another building (leftmost) is not able to be separated from two others using the "all else being equal" facts alone (Figure 5.4). Expert opinion can then be sought to resolve whether the leftmost building rated $[0, 1, 1]$ should be next-most-risky after the $[1, 1, 1]$ rated building, or after the $[1, 0, 1]$ building, or even last in the ranking. The decision should be based on consideration of the relative importance of height versus cladding extent versus egress: if we were to believe that building height was a predominant concern, the $[0, 1, 1]$ building it would be last, whereas if height is less important than cladding extent the $[0, 1, 1]$ building would be ranked second, or if a building being short is important but not influential enough to make up for egress issues then the building may be ranked third. Whatever the decision is, once made we will be able to form a list of buildings by decreasing risk.


Figure 5.4: Height and egress facts can be combined to give a network of buildings by risk

This example illustrates most of the key features of our method for ranking buildings for cladding rectification by fire risk.

1. We select risk factors;
2. We apply a sequence of measurement values within each factor typically but not necessarily after transforming values to a binary zero-one scale;
3. We deduce incontrovertible facts about building risk ordering from within the risk factors;
4. We source expert human judgement to resolve the relative risk between buildings with combinations of two or more risk factor values that cannot be ranked using the facts alone.

Further efficiency and robustness in the method is attained by considering all buildings with the same risk ratings together as a *cohort* of equivalent buildings, rather than as individual buildings. When the method is applied, most of the buildings-by-risk sequencing comes from the application of the facts. Across the full set of buildings only a few dozen expert decisions are needed in order to fully resolve building/building-cohort ordering by risk (which we will tend to refer to as *cohort sequencing* from this point onwards). The result is a ranking for which:

- every risk sequencing decision has a complete logical basis that stems from mathematics and reasoning;
- any pair of buildings in the ranked list can be compared and their relative positions explained in full by reference to facts and particular judgements by experts[4];
- new buildings can often be inserted into the ranked list without any additional ranking judgements being required.

## 5.6 Selection of RAT variables and risk factors

Our chosen cohort sequencing method for the CRPM can be applied using an arbitrary number of risk factors. However, working through the decision process will become more complicated as the number of factors increases. During methods development and SME panel consultation it became clear that six to ten risk factors would optimise the balance between faithfully assessing risk and adding undue complexity which could lead to extended periods of human deliberation, difficult-to-detect ranking anomalies, and relative ranking decisions that may be harder to explain. The final system of variables consisted of nine measures:

- Six risk factors for cohort sequencing:
  - Five of which were taken from the RAT;
  - One which is a new binary yes/no variable `single exit with cladding` about cladding-and-exits that combines information from RAT and other sources. This variable was newly-devised for the CRPM and resulted from discussions between SMEs, CSV and CSIRO;
- Three risk factors used for creating mutually-exclusive *groups* of buildings, for which the cohort sequencing was carried out independently:
  - One new risk measure `maximum SOU` (Section 5.6.2) the value of which was assigned to each building by the expert panel over the course of several weeks;
  - The RAT variable `Automatic.suppression..sprinklers`, the value of which was mapped into a zero-one binary variable indicating whether SOU were protected internally by sprinklers or not;
  - Building number of storeys above ground, the value for which was mapped into a zero-one binary variable `building.height` indicating whether the building had up to eight storeys (value zero, "short") or nine or more storeys (value one, "tall") above ground level including the ground floor.

The process for this selection of measures is described chronologically in Appendix B.1. The differing quality and usefulness of each RAT variable was considered through this process, and the justification for variables that were ultimately selected follows.

### 5.6.1 Building height and protection with sprinkler systems

In the stock of Class 2 residential buildings that are in scope for CSV there are some very tall buildings in the Melbourne CBD and inner suburbs, higher buildings typically in the six to twelve storey range across the metropolitan footprint, and numerous smaller buildings down to three stories high (even shorter buildings are not in scope). A division between tall (nine storeys and above) and shorter buildings in particular is useful and advisable because these are substantially different populations of buildings.

- It is stated by our panel of experts and others involved in building safety that fire in the upper levels of tall buildings, above 25m from ground level, cannot usually be successfully suppressed using ground level firefighting appliances.
- Taller buildings typically have concrete cores containing fire stairs and add structural strength and give residents good protection against fire. Shorter buildings typically lack this feature, especially those below five storeys.

The presence or absence of sprinklers that can suppress fire within SOU is also a pivotal difference between buildings, and interacts with building height.

- Sprinkler systems that protect the interior of SOU can inhibit the propagation of fire from an originating SOU onto the façade (this process was often referred to as "flashover" by the expert panel).
- Sprinkler systems increase occupants' survivability once fire has entered SOU due to flame and smoke

[4] This is not a property that can be guaranteed by other popular decision analysis methods that are based on factor weights

suppression.

When sprinkler protection extends to balconies (sprinklers) and to façades ("drenchers") there is increased risk reduction compared to apartments-only systems. Only a minority of buildings have such systems and we do not focus on the risk reduction premium they can deliver in part because whole-of-building coverage and effectiveness is uncertain. Not all buildings have sprinklers within SOU: many smaller buildings do not have them. Carparks integral to the building have sprinkler systems: this is the amongst the lowest available level of sprinkler protection and is not considered here to qualify a building as being sprinkler fitted.

If we were to create one ranked list of buildings that interleaved these two building height types (tall, short) and two building in-SOU sprinkler system types (yes, no) then this would be unfavorable because:

- The relative importance of different risk factors (such as egress provisions and firefighting provisions) changes with height and sprinkler considerations.
- The dependence of fire outcomes on the flammability of cladding differs between tall and short buildings. Tall buildings can have potential impacts on dozens of SOU within a short time if cladding is extensive and highly flammable. Extensive fire propagation shorter buildings typically requires more sideways fire spread over the façade and is more likely to be coincident with the engagement of on-balcony materials and SOU interiors, and as such has some reduced dependence on the specific façade material.
- CSV may seek to implement different assessment processes, eligibility criteria and work authorisation processes for the different building types.

Relative-risk judgements between very dissimilar buildings will be prone to error and argument. Essentially we should be avoiding apples-to-oranges comparisons and therefore should form multiple ranked lists rather than intermingle them. Three different lists emerge from this logic:

1. **SPRK-TALL** Tall buildings (9 storey and upwards) *with* sprinkler systems protecting SOU internally
2. **SPRK-SHORT** Short buildings (8 storey and less) *with* sprinkler systems protecting SOU internally
3. **NSPRK-SHORT** Short buildings *without* sprinkler systems protecting SOU internally

These lists will be further subdivided by the a threshold value on maximum foreseeable fire loss `max SOU` (Section 5.6.2) and buildings sequenced within these lists according to their cohorts defined by risk factors. The sequence of buildings within a cohort is not a concern.

### 5.6.2 Fire outcome data

An issue with the RAT and other assessment data when it comes to building risk ranking is that there is no information that directly articulates the consequences of a fire. For example, we have measures of egress provision (as an "input" to fire consequence) but this does not really indicate the outcome(s) of fire. We have information on cladding type and configuration, but not only is the latter ambiguously defined in the RAT, the consequences of fire will remain inferred rather than directly estimated or measured. We seek a direct measure of fire consequence which is meaningful and also practical to estimate retrospectively to the building assessments which have already been undertaken over the course of several years.

The risk objective of avoiding injury and fatality principally focusses our attention on the period of time after fire ignition (on the façade or internal to a building) during which occupants have not begun or completed evacuation. A key part of the danger from combustible cladding systems comes from the speed at which the façade can be engulfed: that is, many apartments can be involved in the conflagration while people may yet to have commenced or completed evacuation of the building. Due to this, and to keep the overall task manageable, we:

1. deemphasize time-since-ignition and instead consider the maximum potential extent façade fire spread;
2. eschew the notion of likelihood and concentrate on worst-case outcomes and therefore on the damage that can be done from any plausible ignition location(s);
3. measure façade fire spread extent in terms of the number of SOU that can be engaged.

This leads us to a measure that we term *maximum SOU* (`max SOU`) and for which the definition is "the maximum number of SOUs that a fire could be spread to via cladding". This measure was introduced earlier in this document, in Section 2.1, where it was explained that the maximum SOU measure:

- Is an integer quantity that will range from zero to the number of SOU contained in a building.
- Is the maximum (worst-case) number-of-SOU that would be directly impacted by fire on/in an interconnected section of combustible cladding, for the worst-case (highest SOU count) plausible locations on the building

façade where fire could engage combustible cladding and be propagated principally by the cladding.

- A fire does not need to be initiated at the plausible worst-case location, it might for example begin in an internal kitchen and spread to the cladding by way of a “flashover” (flame or heat transfer) through a window opening.
- An interconnected section of combustible cladding does not need all surfaces/panels to be physically connected (adjacent). Rather, each surface/panel needs to be sufficiently proximal to others to enable fire to carry between them by flame, radiant heat or the burning of other façade materials.
- Although it is entirely conceivable that a fire event on a building may result in the consumption of two non-interconnected sections of combustible cladding by fire because of fire propagation through the interior of the building, the maximum SOU measures does not add the SOU of these sections together, but instead is the SOU count of the maximum section.
- It is only possible for a building’s maximum SOU to equal the number of SOU in that building if: (i) all SOU have external walls; (ii) every SOU has combustible cladding on one or more of these walls; (iii) one interconnected section of combustible cladding can span every SOU.
- It is only possible for a building’s maximum SOU to equal zero if no SOU has combustible cladding on one or more of its external walls.

The value of `max SOU` is assessed by the expert panel using pre-existing data including RAT assessments, streetview and satellite imagery, and detailed engineering/architectural reports (typically referred to as “iAuditor” and “due diligence” reports, and which are part of CSV processes) using a building-by-building method[5]:

1. View each elevation for horizontal and vertical cladding configuration
2. Identify the locations on the building where combustible cladding connected the most apartments
3. Assume a cladding fire would ignite in the worst case location (ground, balcony or flashover fire).
4. Estimate the number of SOUs that might be affected by the cladding fire in the early stages of the event.

Marked-up photographs and diagrams were recorded for each building, usually by way of computer screen capture images (i.e., screenshots), to inform revision and auditing of the Max SOU assessments. Examples of these are illustrated in Figure 5.5.

### 5.6.3 RAT variable inclusion and exclusion

We have already noted that the quality and utility of RAT variables does vary. When this knowledge is considered in light of the proposed cohort sequencing approach and the benefits of having some parsimony in risk factor selection, we find that some of the RAT variables are better to exclude from consideration in cohort sequencing. These measures retain residual value in the overall prioritization process:

- Such variables’ values have contributed to the overall risk rating via the RAT, from which buildings are introduced into the risk prioritization process in the first instance;
- The variables should continue to be utilized in downstream consideration of risk reduction, for example when seeking buildings that have close proximity between combustible cladding and adjacent structures.

As a result of iterative discussions involving the expert panel, the RAT variables[6] and their rationale for inclusion and exclusion from the cohort sequencing are as follows:

1. `Number of storeys` is **included** and is used to partition buildings into different lists as described in Section 5.6.1.
2. `BCA class` was utilized only for qualification of a building into the process (by being Class 2) even though the other class information may have some information content for fire risk (i.e., that there are certain facilities and/or activities present).
3. `Number of occupants / sole occupancy units` is **included** because it is an indication of the number of people that may be at risk from a façade fire.
4. `Types of cladding present` is **included** because it helps to indicate the façade fire potential. It has poor discriminatory power (there only being a very small number of buildings that are in scope, of “High”

[5] As described collectively by the CSV team when consolidating their assessment work in February 2021

[6] We are exclusively considering RAT Version 12 here, because we have data for the vast majority of buildings relative to this version of the RAT

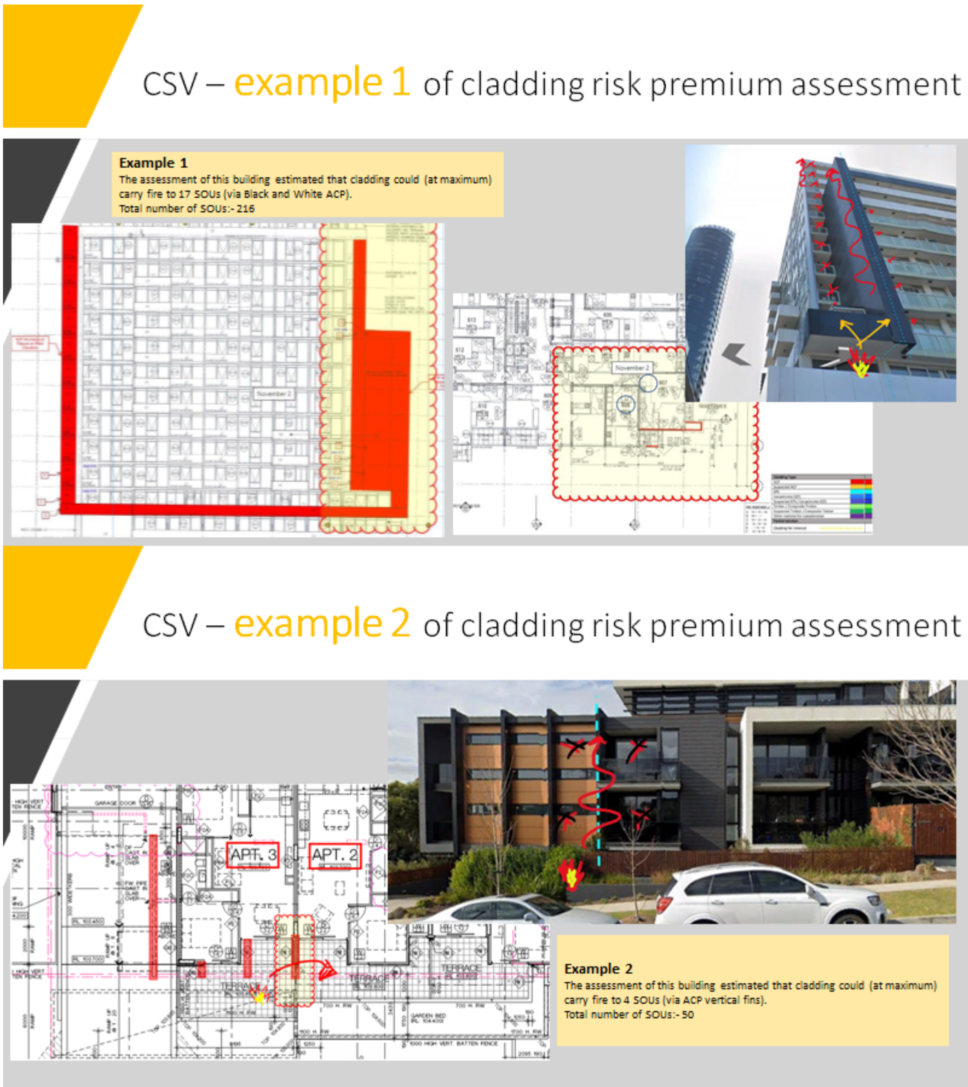



Figure 5.5: Example plan/elevation markup and screen capture from Max SOU assessment (from presentation slides prepared by CSV in February 2021)

RAT risk rating, and cladding that is sufficiently fire rated) but is considered to be measured reliably and differentiates a few particular buildings.

5. `Automatic suppression / sprinklers` is **included** and is used to partition buildings into different lists as described in Section 5.6.1.

6. `Extent of combustible cladding` is **excluded** because this data point is superseded by a more comprehensive appraisal within our `max SOU` estimate.

7. `Configuration of cladding` is **excluded** because this data point is superseded by a more comprehensive appraisal within our `max SOU` estimate and also because the values are ambiguously defined[7].

8. `Proximity of cladding to potential ignition sources` is **excluded** because consideration of potential ignition locations is part of our `max SOU` estimate.

9. `Fire rating of external walls (behind cladding)` is **excluded** because less than 20% of buildings are assessed as having fire-rated external walls but according to the expert panel many more buildings might have had such but assessors did not have sufficient information to be certain.

10. `Risk of cladding fire to or from adjacent buildings` is **excluded** because it was arguable

[7] For example, when is “broken vertical” implying “unbroken horizontal” or otherwise?

whether building-to-building fire propagation would be a sizeable injury/fatality risk (as opposed to an economic risk), the rating did not make it clear which proximal buildings' surfaces were combustible cladding or otherwise, and there are few in-scope buildings that are directly adjacent to each other. Building proximity remains a pertinent issue particularly from a likelihood perspective. Buildings that are within 3m of another will be identified as such within CSV's priority lists so that decision-makers can investigate and gauge the potential on a building-by-exception basis.

11. `Windows, doors, or other openings adjacent to cladding` is **excluded** because almost every building exhibits openings adjacent to cladding.
12. `Insulation type behind cladding` is **excluded** because few buildings are assessed as having fire-resistant insulation behind cladding and according to the expert panel assessors often did not have sufficient information to be certain of the insulation types and extent.
13. `Fixing method` is **excluded** because the cladding fixing method is often not easily assessed on a completed building, and where the method was unknown the scoring reflects a poor fixing method. In addition there seems not to be a consensus view in the industry about the effect of fixing method on fire establishment or propagation, although in National Fire Protection Association (NFPA) [2018] arguments are made that looser fixing methods pose higher risk.
14. `Egress provisions` is **included** as a highly important variable reflecting the potential for injury or fatality.
15. `Speed of Evacuation` is **included**, ditto.
16. `Fire fighting provisions` is **included**, ditto.
17. `Active systems connected to a monitoring agency` is **excluded** because a building with some risk of cladding fire should not be permitted to be without such provision.
18. `Essential safety measure maintenance` is **excluded** because a building with some risk of cladding fire should not be permitted to be in anything but the best state of maintenance from the perspective of essential safety measures. Deficiency in approach in this regard will not be fixed by cladding rectification.
19. `Building management, 24/7 onsite security or warden system` is **excluded** because the current and future state of this variable is not a building technical issue, is not in CSV's control, and therefore should not be part of risk prioritization.

The type of cladding involved in the fire affects the assessment of `max SOU` loss mostly through consideration of the height and width of non-combustible materials that a combustible cladding fire spreading on a façade could bridge. The type of cladding also affects our view on relative risk especially on larger buildings where highly flammable cladding is seen by the expert panel as trumping most other risk factors. Cladding being proximal to egress points carries a particular premium in the RAT assessment guidelines. Furthermore we incorporate an additional single-exit-with-cladding risk factor which was assigned to each building by CSV using various information (mainly iAuditor reports, as we understand it) for the purpose of risk prioritization (i.e., for this project).

Fire/heat chimneying effects and local wind effects are recognised to potentially accelerate the spread of a fire and influence its directions of propagation. This is not easily assessed for all buildings in a comprehensive way. Nevertheless these effects were taken into account during the `max SOU` estimation, where the bridging of air gaps by flame and radiant heat as well as the "licking" of flames around edges and corners (e.g., spandrels between floors) was considered.

## 5.7 Upper and lower division of lists

The distribution of the `max SOU` measure values over the three lists (SPRK-TALL, SPRK-SHORT and NSPRK-SHORT) showed that there are many buildings with quite small values of `max SOU`, say, three SOU or less, and a select number that pose much greater total risk. This is illustrated in Figure 5.6 where the `max SOU` data is plotted for SHORT buildings with and without sprinklers. The median and mean `max SOU` for non-sprinkler buildings is lower because these buildings tend to be smaller in footprint and height. In each case we have many buildings with only minor overall potential impact due to combustible cladding (i.e., one or two SOU fires) and then others with potential façade fires which would be events with much greater gravity.

We can consider a threshold of `max SOU` that is dependent on the list (SPRK-TALL, SPRK-SHORT and NSPRK-SHORT) and which partitions the list into "upper" and "lower" components. From a risk ranking perspective this can be helpful because relative risk judgements between building cohorts (which will be based on the six risk factors) might differ between higher and lower `max SOU` buildings within the same list. This may be the case, for example,

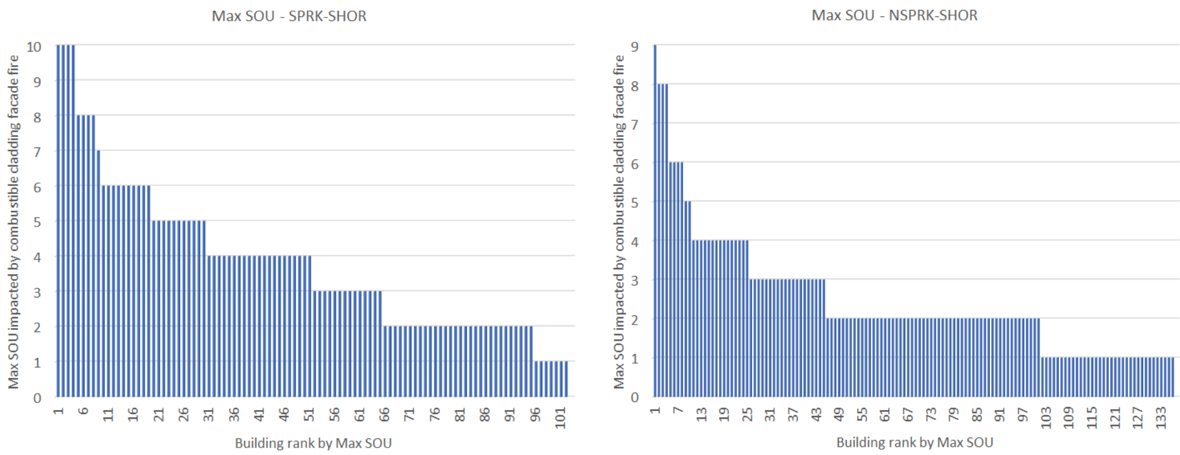



Figure 5.6: Distribution of the Max SOU values for SHORT buildings (data from December 2020)

if sprinkler system capacities might be likely to exceeded when the number of SOU engaged in a fire approaches a certain `max SOU` value. As a side effect, considering higher and lower `max SOU` buildings separately provides us with replications of the relative risk judgement process. This facilitates error-checking and logic-verification activities because differences in comparable decisions made for different subsets of buildings (i.e., between any two or more of the six divisions across the three lists in total) can be questioned as to whether they are correct/accurate (therefore a difference which is intended) or anomalous (therefore a difference which is arbitrary or in error).

It was demonstrated to be the case (through guided application of the method by the SME panel and then subsequent analysis) that the upper and lower divisions of the same list did not actually give rise to different relative orderings of cohorts by risk factors when the method was applied. This was an interesting outcome which might not hold under all future circumstances — either because the expert panel changes its view in future, or there are new cohorts which elicit a judgement from experts that gives a divergence between upper and lower divisions of one or more lists (noting that only 79 of the 384 potential cohorts in total across the three lists had one or more buildings assigned to them, meaning that many cohort-to-cohort comparisons have not been explored yet). Major divergence was apparent in sections of the cohort sequences for the three lists (refer Section 6) because of tall-versus-short and sprinkler-versus-non-sprinkler building differences.

In analysis after the cohort sequencing method was applied we identified three main cases of discrepancy between sub-lists (refer Appendix C.1 for more detail about this). This demonstrated the value of replicated applications of the method. Part of one of these discrepancies was attributed to logical error and reversed, and the other discrepancies stood as intended, logical and justifiable differences. Importantly however, one would not split lists into upper and lower divisions solely to permit cross-checking via replications of the relative risk judgement process. If there was not a valid reason for an upper and lower division, then for robustness it would be better to randomly select several subsets of cohorts ensuring that there were non-null intersections between the selections, do the priority ordering for each subset, and then compare the relative order within the intersections.

The splitting of each list into upper and lower divisions essentially yields six lists, and when labelling building cohorts and applying the methods a three-part list identification was used. The suffixes UPR and LWR were applied to the aforemention three lists' labels, to give SPRK-TALL-UPR, SPRK-TALL-LWR, SPRK-SHORT-UPR, and so on.

The `max SOU` threshold that is used to partition UPR and LWR divisions of the lists can be treated as a parameter and does not need to be "locked in" prior to the risk network resolution step in the risk prioritization method (that is, the step of creating an ordered list of cohorts out of a network of facts, as described in Section 5.5). With reference to Figure 5.6 we could choose thresholds from a relatively wide band of SOU and probably not affect any cohort sequencing differences that may exist between LWR and UPR divisions. As already noted, such differences did not emerge anyway, when we applied the risk network resolution method with the expert panel. For (within SOU) sprinkler-fitted buildings we proceeded initially with a threshold of six SOU between UPR and LWR, but over time (by January 2021) the threshold choice was reduced by CSV and the expert panel to four SOU. For non-sprinkler buildings the threshold was initially three SOU[8].

[8] That is, UPR was six or more SOU for SPRK and three or more for NSPRK.

A threshold on `max SOU` can also be used for other purposes. CSV has done this to split lists into buildings which will be included in the cladding rectification program (those with `max SOU` equal to or greater than a threshold) and buildings that will not be (those with `max SOU` less than a threshold). *This is a program management decision by CSV and not an intrinsic component of the methods that have been developed*. The thresholds used for this did happen to be the same ones that were used for list division. Once again this is an artefact of CSV program management decision making and it need not have been the case that the same threshold values were used for these different purposes. The value of `max SOU` can and should be used for other prioritization activities such as the promotion of buildings with very high `max SOU` values into higher positions in priority lists, or defining successive bands of `max SOU` values and then forming batches of building rectification works over time (according to decreasing value of `max SOU` between bands).

In future it may be the case that a new middle tier of building height/size should be defined. This might take buildings on either side of the present 25m height threshold, or only those buildings that are immediately below it (6-8 storeys) or above it (9-12 storeys). On the one hand there are potentially differences between the smaller and the medium-sized buildings which lead to different cohort orders, this stemming from differences in the relative influence of risk factors. On the other hand, mid-sized apartment buildings (in, say, the 6-12 storey range) and large CBD tower blocks are not ideally comparable either. Also, for the purpose of administering a cladding rectification program there may be value in exploring a middle division of each group's list, i.e., between UPR and LWR. This could assist in identifying buildings for partial treatment or for a later tranche of treatment. Counter arguments for introducing new levels of building height or relative risk include that we can be left with groups of buildings within which there may not be many members, and that experts may struggle to manage the additional complexity especially with respect to ensuring the consistent application of building fire risk principles to the prioritization and ranking processes.

# 6 Applying the method

The method application at a high level was illustrated within Figure 5.1. There are two relevant workflows, one relating to developing priority rules (constituting the "cohort sequencing phase") and the definitions for building risk vectors (constituting the "design phase", beyond the design of the fundamentals of CRPM), and the other workflow is for applying the rules to a population of buildings (i.e., using the CRPM to make decisions). Information about the population of buildings (at a certain point in time) is used to inform the first workflow and it is clearly the core subject of the second. Naturally, during research activity for the project the approach and workflows were arrived at iteratively using analyses, meetings/workshops, proposals, debates and trial runs. This exploratory and iterative period has some interesting aspects and is the focus in parts of the appendices. What is described here is the resulting approach and workflows at the time of project completion. When discussing the development and application of the CRPM in practice, the focus is on the workflows notion rather than the (three) phases description of the CRPM.

The rule development workflow is:

1. Select risk variables from those available in the RAT and/or from other sources;
2. Select the risk variables which will divide the population of buildings into distinct lists (these turned out to be building storey count, sprinker system capability, and `max SOU`);
3. For some or all buildings (i.e., a sample or the full population), associate each building with its set of risk factors and values, which we will term its *risk vector*;
4. Form building cohorts using the building risk vectors, i.e., all buildings in a cohort have identical risk vectors;
5. Create materials which convey illustrative examples of each building cohort, to inform expert judgements;
6. For each distinct list of cohorts, use a software tool taking this list as input and:
   (a) Form *dominance graphs* which contain a node for each and every cohort, and which link pairs of building cohorts that have predecessor-successor relationships derived from "all else being equal" logic;
   (b) Iteratively, consider as "active" all cohorts that are in the dominance graph and which do not have predecessor cohorts, i.e., which are presently *non-dominated*;
   (c) Select one of the "active" cohorts to be next in the list of cohorts ranked from highest to lowest relative risk. Any building in the selected cohort is judged by the expert panel to present no less worst-case risk compared to any building in one of the other active cohorts.
   (d) Remove the selected cohort from the dominance graph, and repeat.
7. Take the distinct ranked lists of cohorts and analyse them comparatively for agreement or anomalies in expert panel decisions

The building ranking workflow is:

1. Ensure RAT data is available and complete for each building;
2. Estimate the value of `max SOU` for each building;
3. Estimate the value of the `single exit with cladding` risk factor for each building;
4. Associate each building with its risk vector;
5. Form building cohorts using the building risk vectors;
6. Apply the priority rules to sequence the set of building cohorts;
7. Translate the building cohort sequence into a ranked list of buildings;
8. Where deemed necessary by CSV over time, add, remove, promote or demote buildings from the ranked list based on new data and informed judgment.

The most complicated part of the CRPM is the rule development workflow Step 6. Appendix B and Appendix C cover this step, and the software used within it, in more detail.

## 6.1 Preparing and synthesizing data

Data is central to the CRPM application. During late 2020 and early 2021, in summary:

1. RAT data was collected and curated by CSV into a tabular form.

2. The RAT data was analysed by CSIRO, including analysis using the R statistical package, and the loading of data into the QGIS software (a Geospatial Information System, GIS) to support spatial analysis and mapping.
3. Max SOU was estimated for about 350 buildings over a period of five weeks by the expert panel. Approximately 120 hours of SME time was consumed in doing this. CSIRO staff attended the first 50 out of around 320 buildings' assessment, to observe and record data from the process.
4. CSV staff analysed building assessment reports in order to determine which buildings had only a single exit and whether cladding was in the proximity of this exit.
5. CSIRO formed the building groups and cohorts using the available information. Cohorts are coded as illustrated in Figure 6.1.

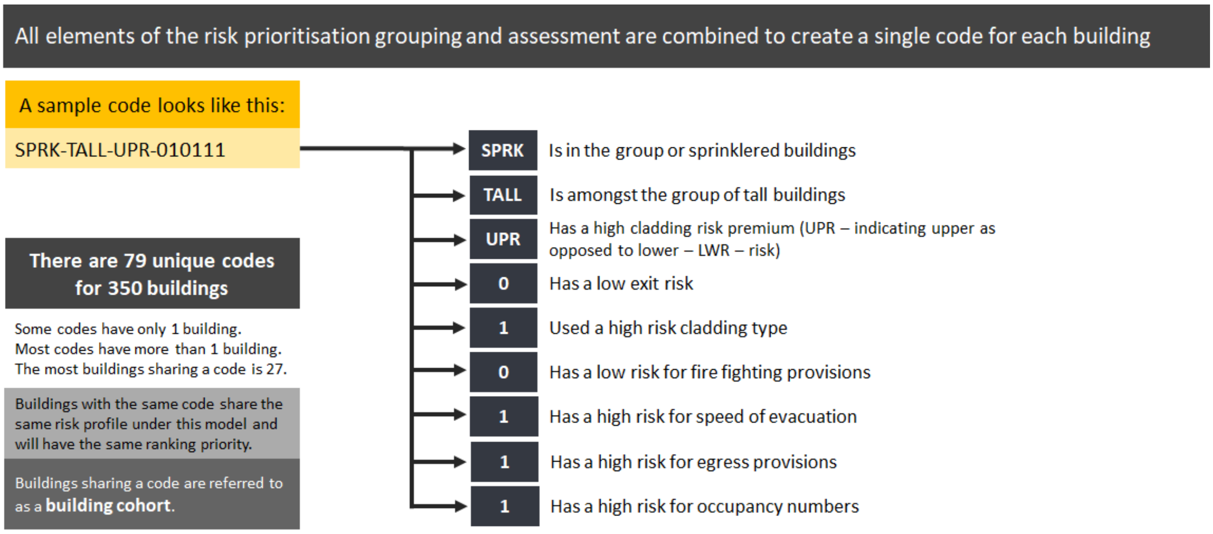



Figure 6.1: Coding cohorts (graphic provided by CSV)

## 6.2 Cohort sequencing

For each of six groups of buildings defined by tall vs short, sprinkler and non-sprinkler, and upper and lower max SOU, the task of the expert panel is then to rank the cohorts within each group from most to least façade fire risk concern. This task is simplified by exploiting a strong mathematical rule of dominance: *that a cohort cannot logically be next in the priority list if there remains another cohort that is no less risky in each of the six risk measures, and is more risky in at least one*.

Purpose-built software presents the candidate next-most-risky cohorts to the expert panel, captures their decision about the next cohort, and updates the set of cohort candidates. The software was "driven" by CSIRO project staff during video-based meetings with the SMEs (this all occurred during periods of significant activity restrictions due to COVID-19) and all participants' attention was directed to the software interface. This software was crucial in keeping the process orderly and error-free. It was also crucial in enabling the expert panel to understand the context of their cohort-priority decisions, revise these decisions, and maintain clarity and consistency in their judgements. More details about the cohort sequencing are found in Appendix B and Appendix C.

It emerged that the choices of next-most-risky cohort were strongly influenced by whether the buildings in a group were over 25m tall (more than 8 storeys) and whether the SOU are fitted with sprinklers. Most notably, firefighting provisions take an increased importance for tall buildings, and evacuation/egress takes an increased importance for short buildings.

The cohort sequencing process results in one-dimensional ordered lists of cohorts within each group. The lists for each of the six building groups are given in Figure 6.2, in which the lower (LWR) cohorts strictly follow the upper (UPR) cohorts in each of these three combined lists. We can take the six ordered lists (which each have a different subset of all of the possible six-digit cohort risk-factor vectors) and form a "master pathways map" of cohort sequences within each group. This map is illustrated in Figure 6.3. Starting at cohort risk factor vector 111111 and following the arrows, it gives the cohort sequence in decreasing order of façade fire risk. The map is a refined result of the cohort ranking process, beyond the individual lists, and infers new information about future (not yet realized) cohort sequence positions within groups using information from other groups. In the map, tall building cohorts follow the pink paths and shorter building cohorts follow the blue and brown/black paths. There are two main pathways through cohorts, with the pathway for buildings less than 25m having a divergence between buildings with-and-without sprinkler systems.

**Tall sprinklered buildings**

| Cohort Codes | Buildings | Rank Position |
|---|---|---|
| SPRK-TALL-UPR-011111 | 8 | SPRK-TALL-01 |
| SPRK-TALL-UPR-011110 | 1 | SPRK-TALL-02 |
| SPRK-TALL-UPR-011011 | 2 | SPRK-TALL-03 |
| SPRK-TALL-UPR-011010 | 1 | SPRK-TALL-04 |
| SPRK-TALL-UPR-010111 | 1 | SPRK-TALL-05 |
| SPRK-TALL-UPR-010011 | 2 | SPRK-TALL-06 |
| SPRK-TALL-UPR-011101 | 1 | SPRK-TALL-07 |
| SPRK-TALL-UPR-011100 | 1 | SPRK-TALL-08 |
| SPRK-TALL-UPR-010100 | 1 | SPRK-TALL-09 |
| SPRK-TALL-UPR-001111 | 1 | SPRK-TALL-10 |
| SPRK-TALL-LWR-011111 | 2 | SPRK-TALL-11 |
| SPRK-TALL-LWR-011011 | 3 | SPRK-TALL-12 |
| SPRK-TALL-LWR-010011 | 2 | SPRK-TALL-13 |
| SPRK-TALL-LWR-010010 | 1 | SPRK-TALL-14 |
| SPRK-TALL-LWR-011101 | 5 | SPRK-TALL-15 |
| SPRK-TALL-LWR-011100 | 0 | SPRK-TALL-16 |
| SPRK-TALL-LWR-001111 | 1 | SPRK-TALL-17 |
| SPRK-TALL-LWR-001110 | 1 | SPRK-TALL-18 |

**Short sprinklered buildings**

| Cohort Codes | Buildings | Rank Position |
|---|---|---|
| SPRK-SHOR-UPR-111110 | 3 | SPRK-SHOR-01 |
| SPRK-SHOR-UPR-111010 | 6 | SPRK-SHOR-02 |
| SPRK-SHOR-UPR-110010 | 3 | SPRK-SHOR-03 |
| SPRK-SHOR-UPR-011110 | 14 | SPRK-SHOR-04 |
| SPRK-SHOR-UPR-001110 | 1 | SPRK-SHOR-05 |
| SPRK-SHOR-UPR-010110 | 6 | SPRK-SHOR-06 |
| SPRK-SHOR-UPR-011010 | 10 | SPRK-SHOR-07 |
| SPRK-SHOR-UPR-110100 | 1 | SPRK-SHOR-08 |
| SPRK-SHOR-UPR-010010 | 2 | SPRK-SHOR-09 |
| SPRK-SHOR-UPR-011100 | 2 | SPRK-SHOR-10 |
| SPRK-SHOR-UPR-010101 | 1 | SPRK-SHOR-11 |
| SPRK-SHOR-UPR-010100 | 1 | SPRK-SHOR-12 |
| SPRK-SHOR-UPR-011000 | 3 | SPRK-SHOR-13 |
| SPRK-SHOR-LWR-111110 | 5 | SPRK-SHOR-14 |
| SPRK-SHOR-LWR-111010 | 4 | SPRK-SHOR-15 |
| SPRK-SHOR-LWR-110010 | 2 | SPRK-SHOR-16 |
| SPRK-SHOR-LWR-011111 | 1 | SPRK-SHOR-17 |
| SPRK-SHOR-LWR-011110 | 13 | SPRK-SHOR-18 |
| SPRK-SHOR-LWR-001110 | 1 | SPRK-SHOR-19 |
| SPRK-SHOR-LWR-010110 | 3 | SPRK-SHOR-20 |
| SPRK-SHOR-LWR-011010 | 12 | SPRK-SHOR-21 |
| SPRK-SHOR-LWR-111100 | 2 | SPRK-SHOR-22 |
| SPRK-SHOR-LWR-110100 | 1 | SPRK-SHOR-23 |
| SPRK-SHOR-LWR-010010 | 6 | SPRK-SHOR-24 |
| SPRK-SHOR-LWR-111000 | 0 | SPRK-SHOR-25 |
| SPRK-SHOR-LWR-110000 | 1 | SPRK-SHOR-26 |
| SPRK-SHOR-LWR-011100 | 1 | SPRK-SHOR-27 |
| SPRK-SHOR-LWR-010100 | 1 | SPRK-SHOR-28 |
| SPRK-SHOR-LWR-011000 | 5 | SPRK-SHOR-29 |

**Short non-sprinklered buildings**

| Cohort Codes | Buildin | Rank Position |
|---|---|---|
| NSPRK-SHOR-UPR-111110 | 1 | NSPRK-SHOR-01 |
| NSPRK-SHOR-UPR-111010 | 3 | NSPRK-SHOR-02 |
| NSPRK-SHOR-UPR-101110 | 1 | NSPRK-SHOR-03 |
| NSPRK-SHOR-UPR-110010 | 1 | NSPRK-SHOR-04 |
| NSPRK-SHOR-UPR-011110 | 8 | NSPRK-SHOR-05 |
| NSPRK-SHOR-UPR-010110 | 1 | NSPRK-SHOR-06 |
| NSPRK-SHOR-UPR-001110 | 1 | NSPRK-SHOR-07 |
| NSPRK-SHOR-UPR-011010 | 15 | NSPRK-SHOR-08 |
| NSPRK-SHOR-UPR-111100 | 3 | NSPRK-SHOR-09 |
| NSPRK-SHOR-UPR-010010 | 8 | NSPRK-SHOR-10 |
| NSPRK-SHOR-UPR-111000 | 3 | NSPRK-SHOR-11 |
| NSPRK-SHOR-UPR-011100 | 10 | NSPRK-SHOR-12 |
| NSPRK-SHOR-UPR-010100 | 1 | NSPRK-SHOR-13 |
| NSPRK-SHOR-UPR-110000 | 1 | NSPRK-SHOR-14 |
| NSPRK-SHOR-UPR-011000 | 11 | NSPRK-SHOR-15 |
| NSPRK-SHOR-UPR-010000 | 4 | NSPRK-SHOR-16 |
| NSPRK-SHOR-LWR-111110 | 6 | NSPRK-SHOR-17 |
| NSPRK-SHOR-LWR-111010 | 14 | NSPRK-SHOR-18 |
| NSPRK-SHOR-LWR-101110 | 0 | NSPRK-SHOR-19 |
| NSPRK-SHOR-LWR-011110 | 23 | NSPRK-SHOR-20 |
| NSPRK-SHOR-LWR-010110 | 3 | NSPRK-SHOR-21 |
| NSPRK-SHOR-LWR-001110 | 1 | NSPRK-SHOR-22 |
| NSPRK-SHOR-LWR-011010 | 27 | NSPRK-SHOR-23 |
| NSPRK-SHOR-LWR-111100 | 3 | NSPRK-SHOR-24 |
| NSPRK-SHOR-LWR-001010 | 1 | NSPRK-SHOR-25 |
| NSPRK-SHOR-LWR-110100 | 3 | NSPRK-SHOR-26 |
| NSPRK-SHOR-LWR-010010 | 7 | NSPRK-SHOR-27 |
| NSPRK-SHOR-LWR-111000 | 5 | NSPRK-SHOR-28 |
| NSPRK-SHOR-LWR-110000 | 3 | NSPRK-SHOR-29 |
| NSPRK-SHOR-LWR-011100 | 11 | NSPRK-SHOR-30 |
| NSPRK-SHOR-LWR-010100 | 2 | NSPRK-SHOR-31 |
| NSPRK-SHOR-LWR-011000 | 27 | NSPRK-SHOR-32 |
| NSPRK-SHOR-LWR-010001 | 1 | NSPRK-SHOR-33 |
| NSPRK-SHOR-LWR-010000 | 7 | NSPRK-SHOR-34 |

Figure 6.2: Building cohorts in rank order (graphic provided by CSV)

The map highlights that cladding type and firefighting provisions have a higher relative importance for tall buildings. This is reflected in the major divergences between the pink and blue/brown/black paths in Figure 6.3. All cohorts with less fire-resistant cladding precede all other cohorts with more fire-resistant cladding for the tall buildings. Rapid spread and higher fire intensity due to less fire-resistant cladding is the key concern here. For short buildings, high-priority cohorts have poorer egress and single exits with cladding (which tall buildings fortuitously did not have). In addition, it emerges from the cohort sequencing that fire safety in tall buildings requires less reliance on external firefighting and more reliance on the building's equipment. This is because firefighters need to enter the building and principally make use of the equipment that is inside.

There is a divergence between the NSPRK and SPRK pathways in the map, and the logic of this divergence is as follows:

- If we do not have sprinklers, we can less afford to have multiple SOU involved in a façade fire because this will lead to there being many locations at which fire could enter the building and potentially run through it. If we have no sprinklers and non-FR cladding, we quickly arrive at a point where there are multiple probable entry points of fire from the façade and into the building. So we must avoid non-FR cladding with elevated priority. When given the choice, we will have to accept diminished firefighting capabilities in return for getting FR cladding. Therefore we have 010110 (non-FR cladding, good firefighting provisions) as higher risk and 001110 (FR-cladding, bad firefighting provisions) as lower risk for NSPRK.
- If we do have sprinklers, then the building has some defence against fire on the façade entering the SOU and propagating through the building. The sprinkler system can be relied upon somewhat to resist fire entry at multiple locations simultaneously. This means that we can de-weight the desirability of combating the rapidity of façade fire growth a little bit, and put more weight on maximising the ability of firefighting/firefighters being able to combat the fire, do rescue, and so on. Therefore we have 001110 (FR-cladding, bad firefighting provisions) as higher risk and 010110 (non-FR cladding, good firefighting provisions) as lower risk for SPRK

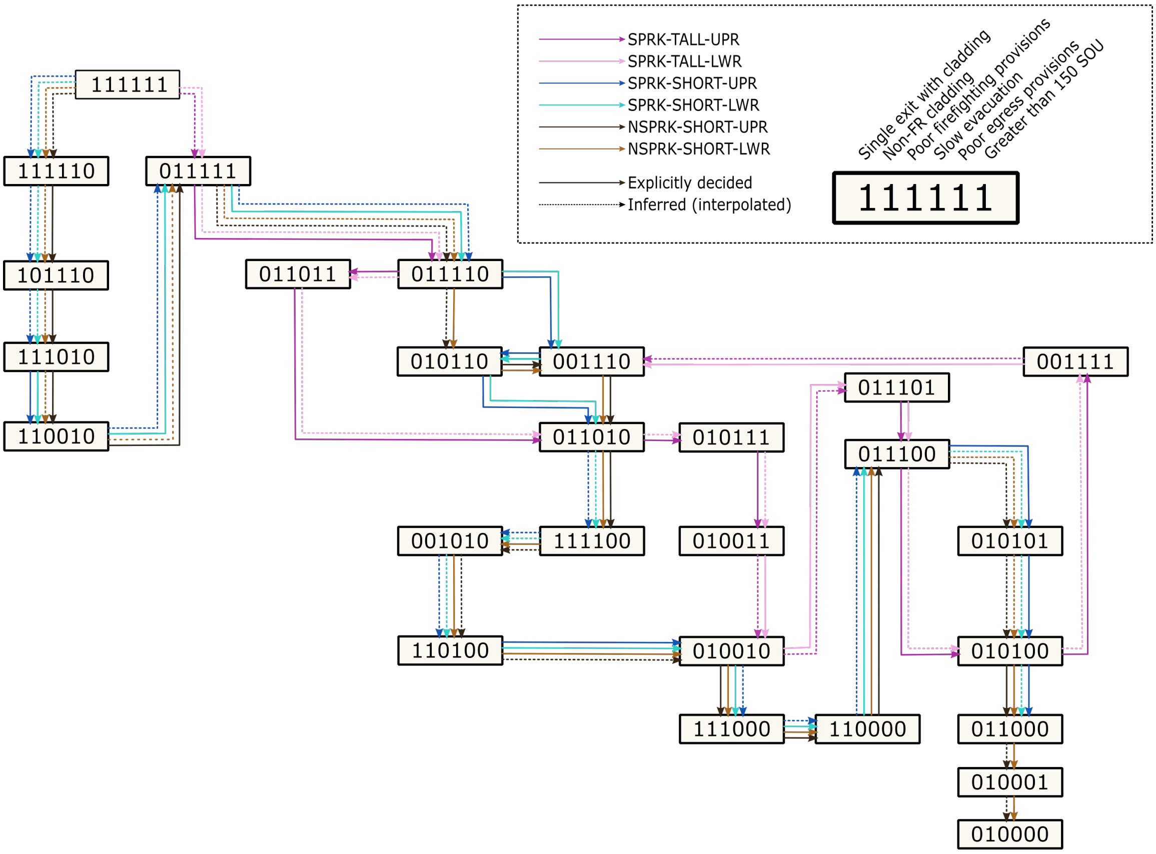



Figure 6.3: Master pathways map

## 6.3 The cladding rectification decision process within CSV

Once the CRPM has been applied, the cohort sequences by building groups and the resulting sequences of buildings are used by CSV in various ways. The principal use is to accelerate the progress of high-risk buildings into and through the necessary steps towards rectification works. The risk prioritization method by no means represents the complete rectification decision process by CSV: the prioritization is not the beginning nor the end of the process. Of particular note is that building re-ordering due to special cases and considerations is always to be expected, and indeed is strongly encouraged in order to make sure that exceptional factors are taken into account. Individual buildings can be promoted or demoted in any of the six group lists. This will occur for various reasons, based on detailed information as it comes together on a pathway from nomination of a building into the CSV program up until the final funding decision and commencement of works.

# 7 Summary, future extensions and improvements

The development of the Cladding Risk Prioritization Method for sequencing cohorts of buildings by their combustible cladding fire risk was a process by which program managers, subject matter experts and data scientists co-created an approach to a difficult problem. The approach is practical and has so far proven valuable in practice. At its simplest the CRPM is about collecting some fundamental data about buildings, using this data to form building cohorts, and sequencing cohorts through applying logically robust "all else being equal" priority rules between building cohorts.

Informed and impartial expert judgement is essential in the applying the CRPM. Experts are needed for assessing the buildings, not least in estimating the worst case façade fire measure `max SOU` which was devised by the team specifically for the CRPM. Experts are also needed to form the priority rules that are used when incontrovertable logic is not sufficient to separate the priority of one cohort from another. The software and workflow that supports the priority rule formation in the CRPM involves experts and data scientists working together in a structured and repeatable process.

The CRPM was designed to make best use of existing data and knowledge about buildings and façade fires, and it was developed over a rather short period of time. Future refinements and extensions could fruitfully address a number of areas:

- The CRPM does not deal with fire likelihood, but rather only with fire plausibility. A future CRPM could bring notions of likelihood into play at least for the most common and relevant sources/locations of ignition (which are kitchens and balconies).
- The CRPM leaves to ad-hoc post-cohort-prioritization steps the consideration of proximity of a building with combustible cladding to other buildings. Some SMEs to whom CSV has introduced the CRPM during a consultation period have commented that this issue would best be addressed more systematically if there was a future revision of the CRPM.
- The division of the building population into "short" and "tall" buildings is a very useful feature of the CRPM. It has since been suggested by SMEs that a third "medium" height category (starting at approximately six storeys) may be useful in future. It has also been suggested by SMEs and others that for rectification program administration purposes a third "middle" band of `max SOU` could be defined for which partial treatments for buildings may be preferred.
- There is ongoing debate amongst building practioners about whether buildings with timber framing should be treated separately when considering combustible cladding, and hence in the CRPM.

It is foreseeable that in future the CRPM could be positioned earlier in a building assessment timeline. For example, in a search for previously unidentified buildings with combustible cladding. In this context the CRPM would no longer be a method applied strictly after the Risk Assessment Tool data gathering, but rather the collection of data for the CRPM could precede the complete RAT data collection. CRPM data could then be used to determine whether buildings' RAT assessment continues or might otherwise be terminated on the basis of the building having insufficient priority. Such an "integrated' use of the CRPM, in contrast to "post hoc" use of the CRPM once the data already exists, might characterise future uses and adaptations of the method for other purposes and in other jurisdictions.

# A Data preparation

Data preparation for creating the binary augmented RAT variables (see Table B.2) consisted of three stages. The first was to create a consistent dataset of RAT variables, since the RAT variable definitions were updated during the building assessment process. The second was to augment this dataset with other relevant data and the third to create binary versions of these variables by choosing a suitable threshold so that variables below the threshold were considered ”low risk” and above considered ”high risk”.

To rank the buildings, we needed a consistent dataset with the same variables measured for all buildings. Since the RAT tool evolved during the building assessment process, not all buildings were assessed according to the same criteria. We worked with data from RAT versions ”11D”, ”12 (17 Indicators)” and ”12 (Current)”. The CSV data analysts performed the conversion to write the older version of the RAT in terms of the current version variables. The converted data was provided to Data61 in a spreadsheet (2020 12 14_RAT Results_V8_V11 Recoding to align to V12.xlsx). Conveniently,for the variables chosen to build the dominance graphs the variable meanings were all identical, so the only change made was to the numerical values that representing the categories so they were all consistent with the version 12 (Current).

The description of how the RAT variables were augmented and converted to binary appears in Appendix B.

## A.1 Estimating maximum SOU

Since a main aim of this project was to minimise the loss of life due to cladding-related fires, it was important to include a variable to describe how dangerous it would be for a fire to start externally to each of the buildings under consideration. To encapsulate this idea, subject matter experts were asked to estimate the maximum number of SOU that were likely to be impacted from a fire starting in the worst possible place on the façade.

We began by asking the experts to assess a small subset of 50 buildings to determine what resources were required and what process the experts would follow to assess all the buildings. This process was captured on a Miro board [9], an online whiteboard allowing collaborators to annotate the same space in real time. For each building assessed, screen shots of the photos used in the assessment were captured and key information from the decision-making process was recorded using (electronic) “sticky notes”. An example is given in Figure A.1.

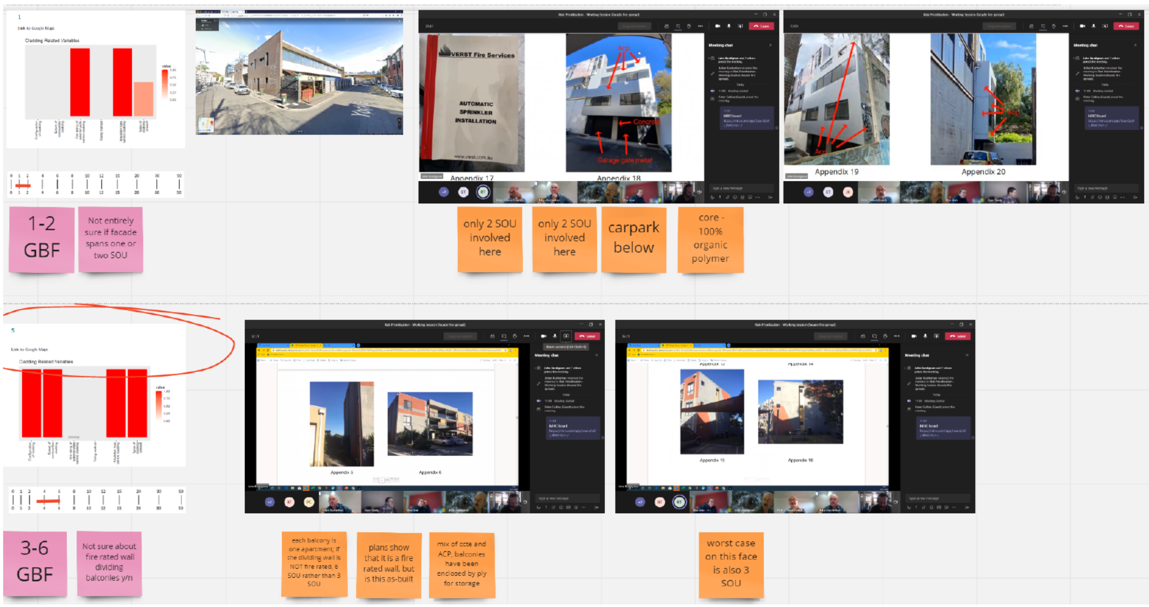



Figure A.1: Excerpt of Miro board used to capture key information gathered and considered when estimating the maximum SOU affected by a fire starting on the building façade.

After the initial set of buildings had been assessed, it was important to standardise the approach of assessing the other buildings, to make sure the maximum number of SOU affected was consistent across all the buildings. A Word document template or *rubric* was created using RMarkdown [10] to organise and record this process. It contained data in the form of tables and plots for each building as well as headings to ensure the same points of discussion

[9] https://miro.com
[10] https://rmarkdown.rstudio.com/

were covered for each building. Since the Word document was editable, it also served as a place to record decisions made when assessing the buildings.

The estimate of the maximum number of SOU affected was used to create different groups of buildings, where a dominance graph was created for each group as explained in Appendix B and is one of the augmented RAT variables in Table B.1.

# B Dominance Graphs

Dominance graphs can be used to weakly order the buildings in the RAT. Dominance graphs are a network where an edge from node A to node B indicates that node A *dominates* node B. In our case, each node represents a *cohort* of buildings which have identical measured properties. One building cohort is considered dominant over another if it has a higher fire risk due to combustible cladding. A dominance graph does not perfectly order the building cohorts from most to least risky, but instead gives a weak ordering. This means that building cohorts that are clearly riskier than others are ordered as such, but there are some cohorts that have an indistinguishable risk. The relative risk of these buildings could be determined by ranking the importance of the variables, something we investigated, but the final procedure chosen was to use subject matter experts to make these decisions.

In this section we cover how we created dominance graphs to give a weak ordering of the buildings in the RAT. First we chose six variables (5 RAT variables and one to augment the RAT data) which represent various aspects of fire risk and converted these into binary variables, where zero denotes low risk and one high risk. We then created a dominance graph by comparing the binary strings representing each type of building. We explored the idea of creating further dominance subgraphs which give a weak ordering within levels of the full dominance graph, to guide distinguishing between buildings with the same number of high risk variables. However, the final method for deciding between these cases was to use subject matter expertise.

## B.1 Variable selection

Variables to describe the risk of fire due to cladding were selected by the subject matter experts. The variables were selected from the RAT variables and additional data gathered by CSV in November 2020 from existing assessments and reports pertaining to the buildings and their locations. We refer to this data as *augmented RAT* variables. Variables were chosen with the aim of having enough information to adequately describe the risk of fire due to cladding, while keeping the number of variables low enough that the dominance graphs were of a manageable size. The list of variables was updated throughout the process, as detailed in the main text. In this appendix, we illustrate the methods using a snapshot of the variables that were in use in December 2020. Nine variables were chosen, and they are displayed in Table B.1. Where the variables are categorical, the levels indicate these categories have been ordered from low to high fire risk.

The augmented RAT variables were converted to binary variables using the cut-offs determined by the subject experts and detailed in Table B.2. We chose to use binary versions of the augmented RAT variables, because it simplified the dominance graphs, with every variable either indicating a low or high risk. The same methods could have been applied to the raw data, as all the variables were ordinal or positive integers, but the dominance graphs would have had more nodes. Choosing binary versions of the variables allowed us to simplify the variables in a way that left their key information intact: how much they elevated the fire of a building.

The buildings were split into six categories, based on the first three variables in B.2: automatic suppression (sprinklers), worst case SOU impact rating, and rise in storeys. A dominance graph was created for each of these six categories, because they represent radically different situations and decisions around which buildings to prioritise would be different for each of the groups. The groups were given the short-hand labels

- SPRK-SHOR-LWR
- SPRK-SHOR-UPR
- SPRK-TALL-LWR
- SPRK-TALL-UPR
- NSPRK-SHOR-LWR
- NSPRK-SHOR-UPR,

based on the cut-offs given in Table B.2. Note that the categories NSPRK-TALL-LWR and NSPRK-TALL-UPR do not appear, since building regulations require that tall buildings have sprinklers.

The remaining six variables were used to create dominance graphs. A dominance graph consists of nodes and directed edges (arrows). A node represents a *cohort* of buildings which have identical values of the binary augmented RAT variables. A directed edge from one node to another indicates that the first cohort of buildings is at a higher risk than the second. Each node is labelled by a binary string representing the values of the binary RAT variables shared by all buildings in that cohort. For example, the binary string ”111000” represents all buildings that have the variables ”One exit with cladding”, ”Types of cladding present” and ”Fire fighting provisions” in the high risk category and the rest of the variables (”Speed of evacuation”, ”Egress provisions” and ”Number of occupants or sole occupancy units") in the low risk category. In the next section , we show how to compare these binary strings to determine which buildings are riskier than others.

## B.2 Dominance graph creation

A dominance graph for the buildings indicates a hierarchy based on building risk. A graph consists of nodes and edges. A node represents all buildings with a fixed binary string. An edge from node A to node B indicates that the buildings represented by node A are at a higher risk than those represented by node B.

To create such a graph, we must define a rule which compares two buildings and indicates which at a higher risk. To determine the relative risk of two buildings, we compare the binary string determined by the values of the binary augmented RAT variables specified in Table B.2. Building cohort A is said to be at a higher risk than building cohort B, if when comparing their binary strings, in all the positions in which they disagree building cohort A has a one and building cohort B has a zero.

For example, the buildings represented by the string "011111" are riskier than the buildings represented by "001111", "011111" and "011101". Therefore, a directed edge is drawn from node "011111" to each of those nodes, as shown in Figure B.2. Note that this property is transitive: if building A is riskier than building B and building B is riskier than building C, then building A is riskier than building C. Therefore, nodes at the top of the dominance graph are riskier than those at the bottom. Note that we only draw the minimal edges required to connect the graph: for example, there is no direct edge from "011111" to "001110", since it is implied that "011111" is riskier than "001110" by the edges from "011111" to "001111" and from "001111" to "001110".

Previously we mentioned that dominance graphs give a weak ordering of the building cohorts. Let us understand this concept using Figure B.2 as an example. The riskiest cohort of buildings are those at the top of the diagram, labelled "011111", so this cohort of buildings appears first in the ranking of buildings to be funded for combustible cladding removal. The dominance graphs shows that this cohort of buildings is riskier than the cohorts "001111", "011011" and "011101", but it does not determine which of these three buildings should go next in the ranking. It is a weak ordering because we know some information about which building cohorts are riskier than others, but there are some for which further information is required to determine the final ranking.

The dominance graphs are used in this project as a decision tool. By adding building to the ranking following the dominance graph from top to bottom, we ensure that buildings that are clearly riskier than others are always prioritised for funding. To determine the final ranking of the cohorts, we traverse the tree from top to bottom, choosing from the *active nodes* which cohort is put next in the ranking. In the case of Figure B.2, the tree has one root node, labelled "011111" and coloured green, which is riskier than all other buildings and, therefore, the only active node. Once this node has been added to the ranking and removed, the three nodes it dominates become active: "001111", "011011" and "011101". Say, based on our domain knowledge, we choose the node "001111" to be next in the ranking. Then the node "001111" is removed from the tree and the node that it dominates "001110" is added to the active nodes: "001110", "011011" and "011101". See Figure **??**. The process is repeated until all the nodes have been ranked.

The dominance graphs for each of the six groups of buildings listed in Section B.1 are given in Figures B.3–B.8.

[11] This value is chosen for illustrative purposes and varied throughout the period this method was applied.

[12] This value was chosen as a proxy for 25 m, the value up to which ground-based fire-fighting is considered effective.

| VARIABLE NAME | DESCRIPTION | LEVELS | DATASET |
|---|---|---|---|
| Automatic suppression (sprinklers) | The presence of a sprinkler system reduces a building's risk score in relation to both the risk of fire spread, and the ability of occupants to exit safely. | • Fully sprinkled including SOU's, balconies and canopies<br>• Fully sprinkled excluding balconies and canopies<br>• Basement carpark only or Protecting exit paths only<br>• No sprinklers | RAT |
| Worst case SOU impact rating | Maximum number of SOU that could reasonably be expected to be impacted by a combustible cladding fire | • Positive integer | Expert panel |
| Rise in storeys | Number of storeys above ground (i.e. not including underground car parks) | • Positive integer | Other |
| One exit with cladding | Indicates whether a building's only exit contains combustible cladding or not. | • At least one exit without combustible cladding<br>• Sole exit to building has combustible cladding. | Other |
| Types of cladding present | Some types of combustible cladding present a lower risk of fire spread and this is reflected with a lower fire spread risk score. Only aluminium composite panels (ACP) and expanded polystyrene (EPS) will impact on the scoring on this criteria. | • $\leq$ 10% PE (polyethylene) content ACP<br>• $\leq 30\%$ PE content ACP<br>• Expanded polystyrene or ACP PE or ACP unclear | RAT |
| Fire fighting provisions | Overall score for the adequacy of fire fighting provisions. These scores should be based on an informed opinion, preferably from a representative of the relevant fire agency, of the overall adequacy of the building's fire fighting provisions. | • Very good<br>• good<br>• fair<br>• poor | RAT |
| Speed of evacuation | Score to describe the time occupants take to leave the building or to enter a safe refuge such as a fire isolated stair without being subject to untenable conditions once a fire has commenced. | • Very good<br>• good<br>• fair<br>• poor | RAT |
| Egress provisions | The adequacy of egress provisions in the building, based on informed opinions by members of expert panel. | • Very good<br>• good<br>• fair<br>• poor | RAT |
| Number of occupants or sole occupancy units | The number of units or occupants influences the potential consequence of a severe fire and the overall ability of residents to exit the building in the event of an emergency. | • 10 units<br>• 11–50 units<br>• 51–150 units<br>• 151+ units<br>OR<br>• 1–30 occupants<br>• 31–150 occupants<br>• 151–450 occupants<br>• 451+ occupants | RAT |

Table B.1: Augmented RAT variables. These variables were selected to create a dominance graph describing the relative fire risk of buildings. The descriptions of the RAT data are taken from Risk Assessment Tool Guidance (public release v12k 20180524).

| VARIABLE NAME | LEVELS | BINARY RISK (0 LOW, 1 HIGH) |
|---|---|---|
| Automatic suppression (sprinklers) | Fully sprinklered SOU (including or excluding balconies and canopies) | 0 (SPRK) |
| | Only basement, car park or exits sprinklered OR no sprinklers | 1 (NSPRK) |
| Worst case SOU impact rating | $\leq 3$ SOU impacted[11] | 0 (LWR) |
| | $> 3$ SOU impacted | 1 (UPR) |
| Rise in storeys | $\leq 8$ storeys[12] | 0 (SHOR) |
| | $> 8$ storeys | 1 (TALL) |
| One exit with cladding | At least one exit without combustible cladding | 0 |
| | Sole exit to building has combustible cladding | 1 |
| Types of cladding present | $\leq 10\%$ or $\leq 30\%$ PE content ACP | 0 |
| | Expanded polystyrene or ACP PE or ACP unclear | 1 |
| Fire fighting provisions | Very good, good | 0 |
| | Fair, poor | 1 |
| Speed of evacuation | Very good, good | 0 |
| | Fair, poor | 1 |
| Egress provisions | Very good, good. | 0 |
| | Fair, poor. | 1 |
| Number of occupants or sole occupancy units | 1-10 units, 11-50 units OR 1-30 occupants, 31-150 occupants. | 0 |
| | 51-150 units, 151+ units OR 151-450 occupants, 451+ occupants. | 1 |

Table B.2: Binary augmented RAT variables. Conversion of selected augmented RAT variables to binary variables, where zero represents low risk and one represents high risk.

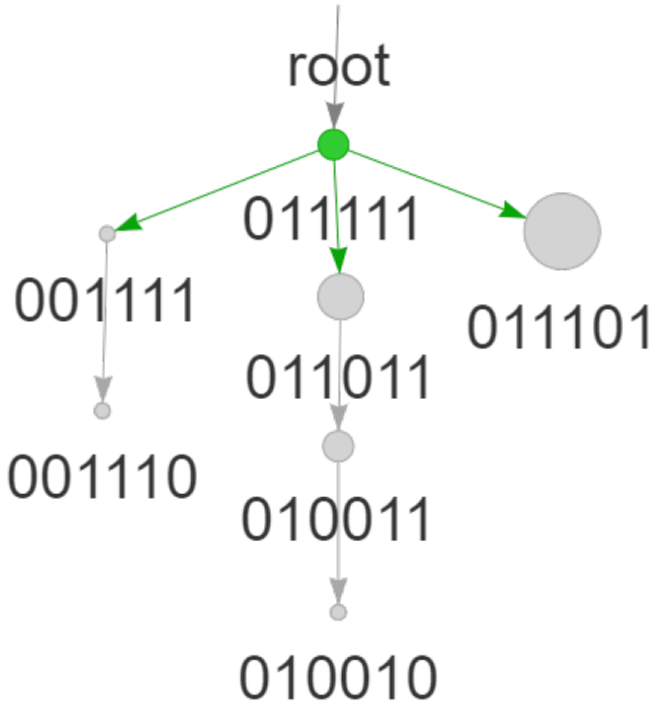
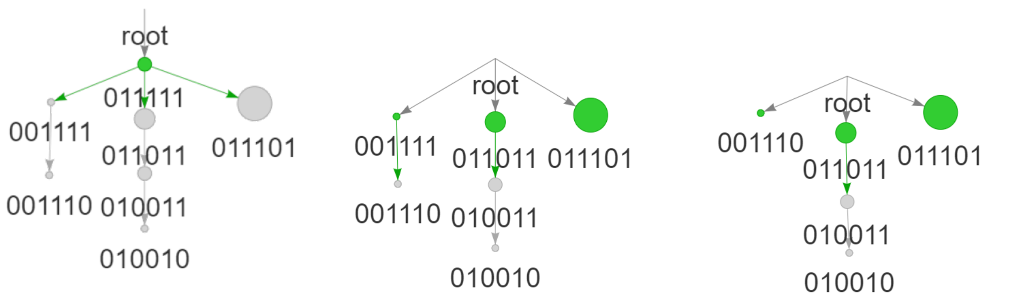



Figure B.1: Dominance graph for buildings with sprinklers, lower number of SOU impacted and large number of storeys (SPRK-TALL-LWR). The nodes represent cohorts of buildings with the same values binary augmented RAT variables, and the size of the node is proportional to how many buildings are in that cohort. The root points to the root of the tree: the green node labelled ”011111”. This node represents the highest risk cohort of buildings, so it is the active node: the node to be chosen next to determine the ranking of building cohorts. Arrows point from nodes representing buildings of higher risk to those of lower risk.




(a) Full dominance graph (b) After first node is removed (c) After second node is removed

Figure B.2: Example of how a ranking is determined from a dominance graph. The green nodes in each figure represent the active nodes: the nodes from which the next building cohort for the ranking is to be chosen. The full dominance graph (a) has one active node “011111”, so this node is chosen first in the ranking. The second dominance graph (b) is the updated dominance graph after the first node was removed. It contains three active nodes: “001111”, “011011” and “011101”. These three nodes are those that were dominated by the removed node. The dominance graph does not give any information about which of these building cohorts is at most risk, so subject matter expertise is used to choose between them. Say the leftmost active node “001111” were chosen, then the ranking would become “011111”, “001111” and the updated graph (c) elevates the node dominated by “001111” to the status of active node. To obtain a full ranking of all the nodes, this process is continued until there are no nodes left in the graph.

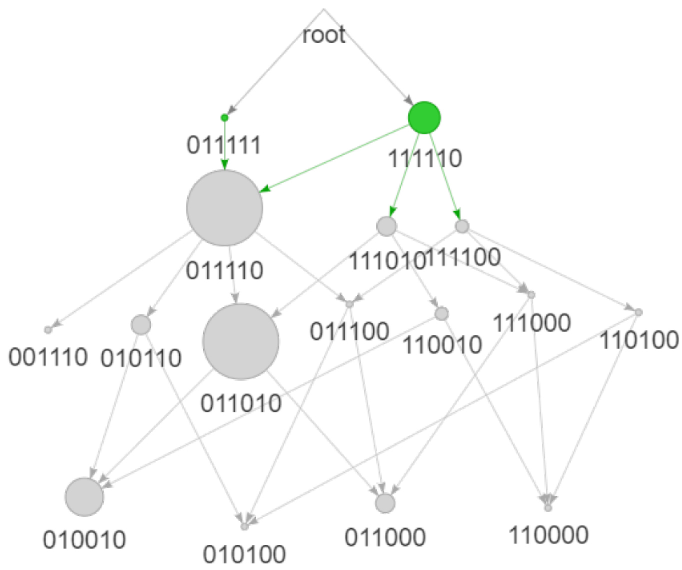



Figure B.3: Dominance graph for buildings SPRK-SHOR-LWR.

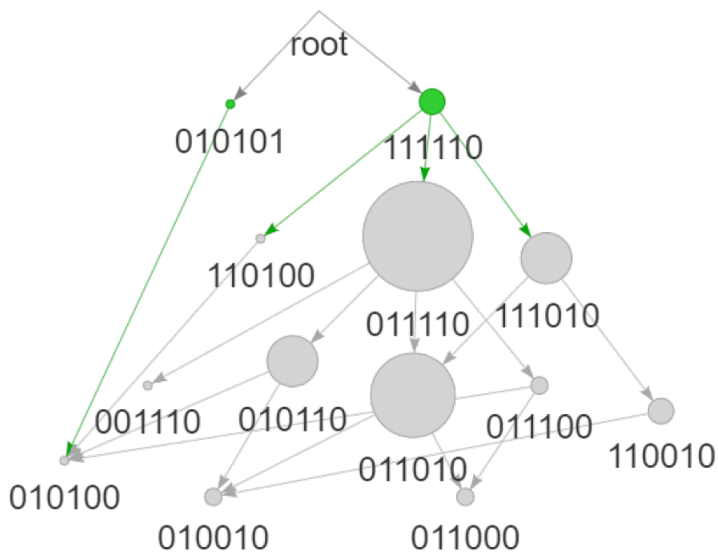



Figure B.4: Dominance graph for buildings SPRK-SHOR-UPR.

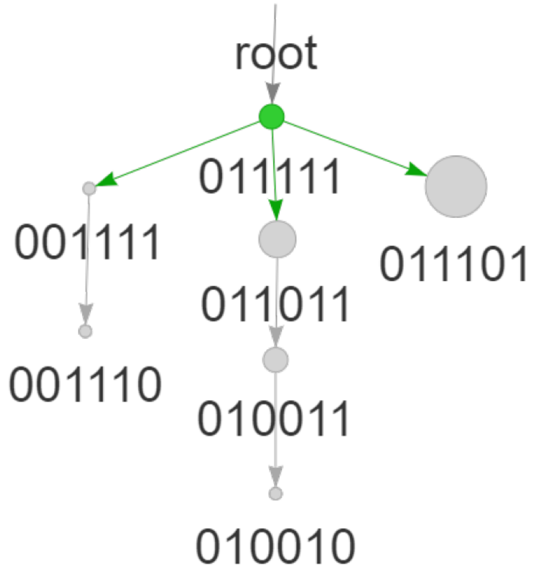



Figure B.5: Dominance graph for buildings SPRK-TALL-LWR.

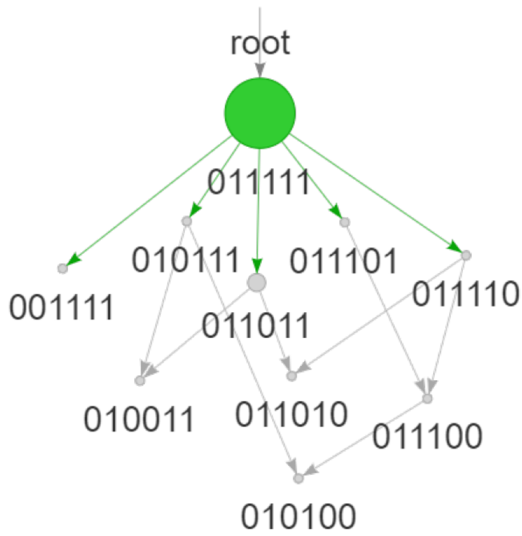



Figure B.6: Dominance graph for buildings SPRK-TALL-UPR.

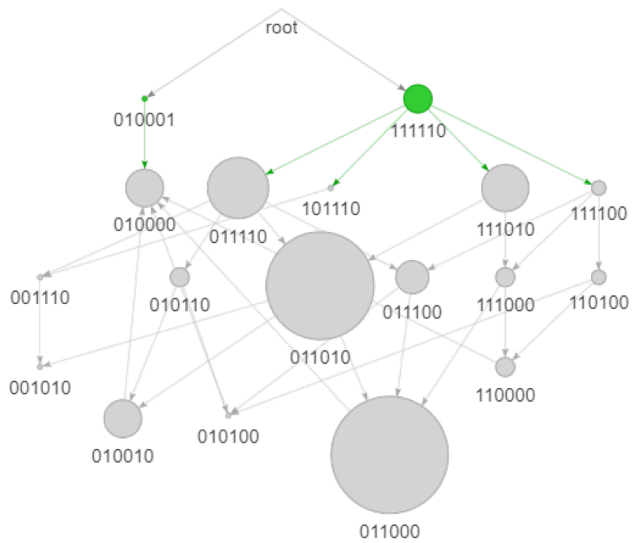



Figure B.7: Dominance graph for buildings NSPRK-SHOR-LWR.

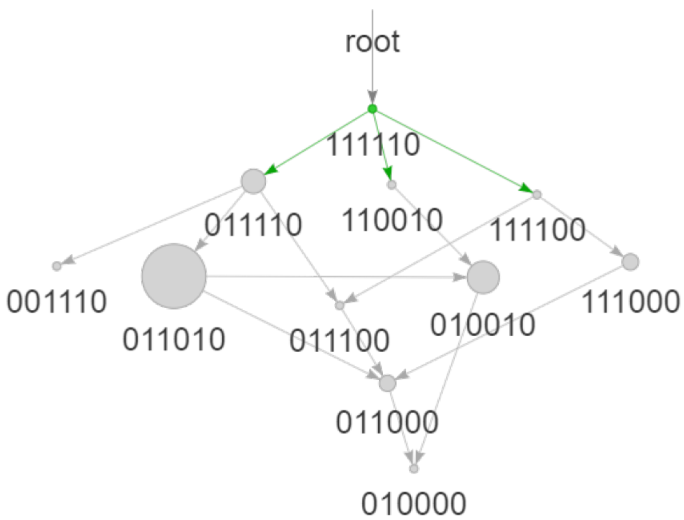



Figure B.8: Dominance graph for buildings NSPRK-SHOR-UPR.

# C Collaborating with SMEs to order cohorts

In this section we describe how the building cohorts were ordered using dominance graphs. Recall from Appendix B.2 that the ordering is obtained by working through the dominance graph from top to bottom, choosing and removing nodes one at a time to create an ordering. At each step the nodes that can be chosen are the active nodes: they have no arrows pointing to them and are indicated in green in all the dominance graphs in this report. This means that a building cohort that is less risky than another cannot accidentally be prioritised over the riskier one. However, decisions need to be made using information extra to what is encoded in the dominance graph to choose between the active nodes.

These decisions were made in a meeting with CSV fire safety experts who made decisions about which cohort to put next in the ordering when there were multiple active nodes. To make sure the dominance graphs were traversed correctly, only removing active nodes, and to automatically record the ordering, we developed an app using RShiny[13], see Figure C.1 for a screenshot. Active nodes (green) are selected for removal using the drop-down menu to the left and the ordering chosen can be downloaded using the download button. Once an active node is removed, the dominance graph automatically updates, promoting the nodes dominated by the removed node to active nodes.

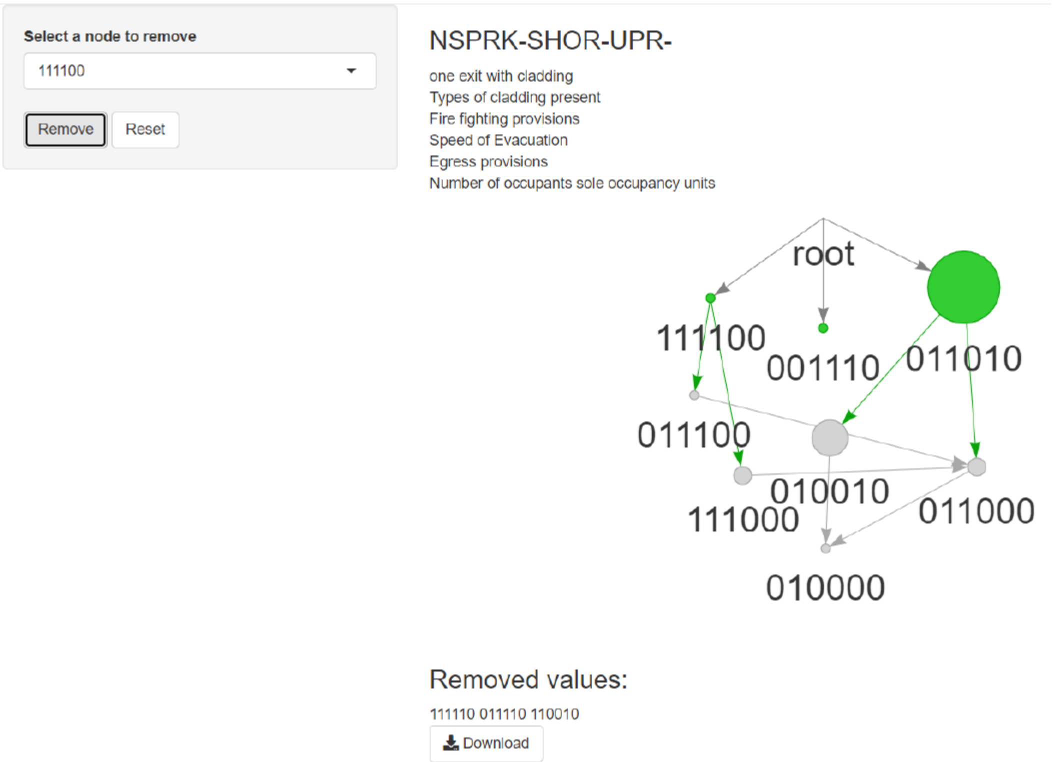



Figure C.1: RShiny app to create ordering from a dominance graph. The active nodes (green) appear in the drop-down menu to the left, so that only active nodes can be removed at each step. The list of nodes which have been removed already are listed at the bottom. Clicking the download button at the bottom of the app downloads the list of nodes that have been removed (in order) to a csv file.

This process of ordering nodes was followed for each of the six dominance graphs Figures B.3–B.8. The final orderings are given in Tables C.2-C.4. Cladding Safety Victoria will determine which buildings received funding based on these lists.

[13] https://shiny.rstudio.com/

| ORDERING |
|---|
| 111110 |
| 111010 |
| 110010 |
| 011111 |
| 011110 |
| 001110 |
| 010110 |
| 011010 |
| 111100 |
| 110100 |
| 010010 |
| 111000 |
| 110000 |
| 011100 |
| 010100 |
| 011000 |

(a) SPRK-SHOR-LWR

| ORDERING |
|---|
| 111110 |
| 111010 |
| 110010 |
| 011110 |
| 001110 |
| 010110 |
| 011010 |
| 110100 |
| 010010 |
| 011100 |
| 010101 |
| 010100 |
| 011000 |

(b) SPRK-SHOR-UPR

Figure C.2: Ordering of building cohorts in groups of short buildings with sprinklers (SPRK-SHOR). Table C.2a contains building cohorts with a low number of SOU expected to be affected by a cladding fire and Table C.2b contains those expected to have a large number affected. The building cohorts at the top of each list are the highest priority for funding, and the upper list is considered higher priority than the lower.

| ORDERING |
|---|
| 011111 |
| 011011 |
| 010011 |
| 010010 |
| 011101 |
| 011100 |
| 001111 |
| 001110 |

(a) SPRK-TALL-LWR

| ORDERING |
|---|
| 011111 |
| 011110 |
| 011011 |
| 011010 |
| 010111 |
| 010011 |
| 011101 |
| 011100 |
| 010100 |
| 001111 |

(b) SPRK-TALL-UPR

Figure C.3: Ordering of building cohorts in groups of tall buildings with sprinklers (SPRK-TALL). Table C.3a contains building cohorts with a low number of SOU expected to be affected by a cladding fire and Table C.3b contains those expected to have a large number affected. The building cohorts at the top of each list are the highest priority for funding, and the upper list is considered higher priority than the lower.

| ORDERING |
|---|
| 111110 |
| 111010 |
| 101110 |
| 011110 |
| 010110 |
| 001110 |
| 011010 |
| 111100 |
| 001010 |
| 110100 |
| 010010 |
| 111000 |
| 110000 |
| 011100 |
| 010100 |
| 011000 |
| 010001 |
| 010000 |

(a) NSPRK-SHOR-LWR

| ORDERING |
|---|
| 111110 |
| 110010 |
| 011110 |
| 001110 |
| 011010 |
| 111100 |
| 010010 |
| 111000 |
| 011100 |
| 011000 |
| 010000 |

(b) NSPRK-SHOR-UPR

Figure C.4: Ordering of building cohorts in groups of short buildings without sprinklers in the apartments (NSPRK-SHOR). Table C.4a contains building cohorts with a low number of SOU expected to be affected by a cladding fire and Table C.4b contains those expected to have a large number affected. The building cohorts at the top of each list are the highest priority for funding, and the upper list is considered higher priority than the lower.

## C.1 Forming the master map

After ordering the building cohorts for each of the six groups, we compared the six orderings to see whether they were consistent with each other. Any differences in the ordering of building cohorts were then checked to understand whether the difference was intentional or not. This was done by hand, grouping the matching cohorts across building groups and drawing arrows to indicate the ordering, see Figure C.5. Every cohort mapped to a letter of the alphabet, since the brain is trained to recognise patterns in Latin characters, this mapping made patterns easier to spot, Figure C.6.

The three potential inconsistencies highlighted by Figure C.6 were:

1. In SPRK-TALL-UPR building cohort 010010 comes before 001110, but in SPRK-TALL-UPR and all four categories of short buildings their order is reversed.
2. In SPRK-SHOR-UPR there is the ordering 110100 $>$ 010110 $>$ 011010, but in SPRK-SHOR-LWR and NSPRK-SHOR-LWR the same cohorts are ordered 010110 $>$ 011010 $>$ 110100.
3. In SPRK-SHOR-UPR and SPRK-SHOR-LWR building cohort 001110 comes before 010110, but in NSPRK-SHOR-LWR the order is reversed.

The major differences between the TALL and SHOR(T) pathways is of course not considered to be an inconsistency, but rather, as a feature resulting from reason.

For the first potentially inconsistent case to be justified, the type of cladding must be more important than the fire fighting provisions and speed of evacuation in tall buildings and the reverse must be true for short buildings. Upon revision, this was deemed sensible by the expert panel, since a more dangerous type of cladding is more dangerous on a tall building, where the fire can spread upwards and affect many people. On the other hand, for smaller buildings, fire fighting can be more effective and, therefore, having good fire fighting provisions is key. It was therefore decided by SME that this difference was meaningful; and also that the higher priority of cladding type should apply for all TALL buildings.

For the second case, it was decided that the second ordering should be used in all building groups. The second ordering gives priority to building with bad egress provisions over those with a single exit, where that exit has combustible cladding. The decision was made that for all buildings, egress provisions takes into account the exits having cladding as well as other factors affecting egress, so it makes sense to give measure priority.

Lastly, for the third case, the ordering used for buildings without sprinklers gave priority to buildings with a dangerous cladding type over those with bad fire fighting provisions and vice versa to buildings with sprinklers. This is because buildings without sprinklers are at a higher risk of the fire entering the building, so having more dangerous cladding which will increase the size of the external fire is increasingly dangerous for buildings without sprinklers.

Having justified or rectified any differences in orderings between the six groups of buildings, we redraw the flow chart Figure C.5 as Figure C.7. To this figure we add dotted lines which interpolate paths through nodes that did not appear in that dataset, but indicate how we would expect that node to be ordered based on the cohort sequences of other groups of buildings. This allows us to compare the trajectories between the building groups. Overall, there are two main paths: one followed by the tall buildings and another by the short. The only exception to that is the ordering of nodes 010110 and 001110 which differ between short buildings with sprinklers and short buildings without sprinklers.

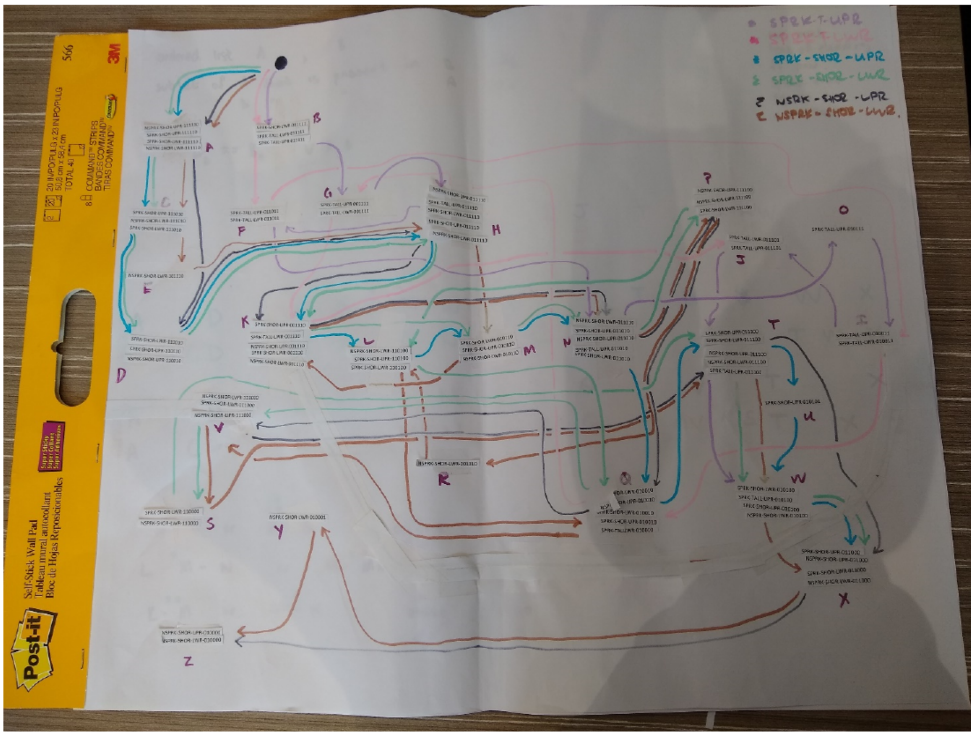



Figure C.5: Master pathways. The orderings of all six building cohorts in one unified map. Each building cohort is labelled by a letter of the alphabet. The corresponding orderings for each of the six groups is recorded in Figure C.6.

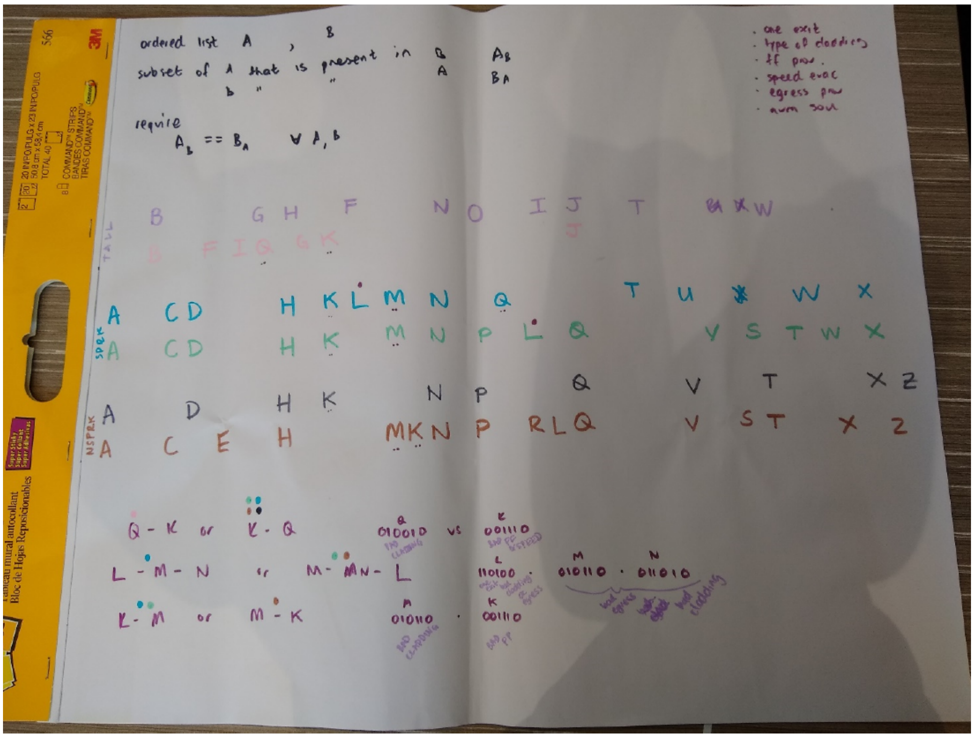



Figure C.6: Comparison of the ordering for the six groups of buildings. Each letter of the alphabet corresponds to a building cohort. The first two lines are the tall buildings, second two short buildings with sprinklers and the last short buildings without sprinklers. Each pair represents the upper and lower lists, those with a low maximum foreseeable loss of SOU and those with a high loss. At the bottom of the diagram, the purple text highlights ordering differences between the lists.

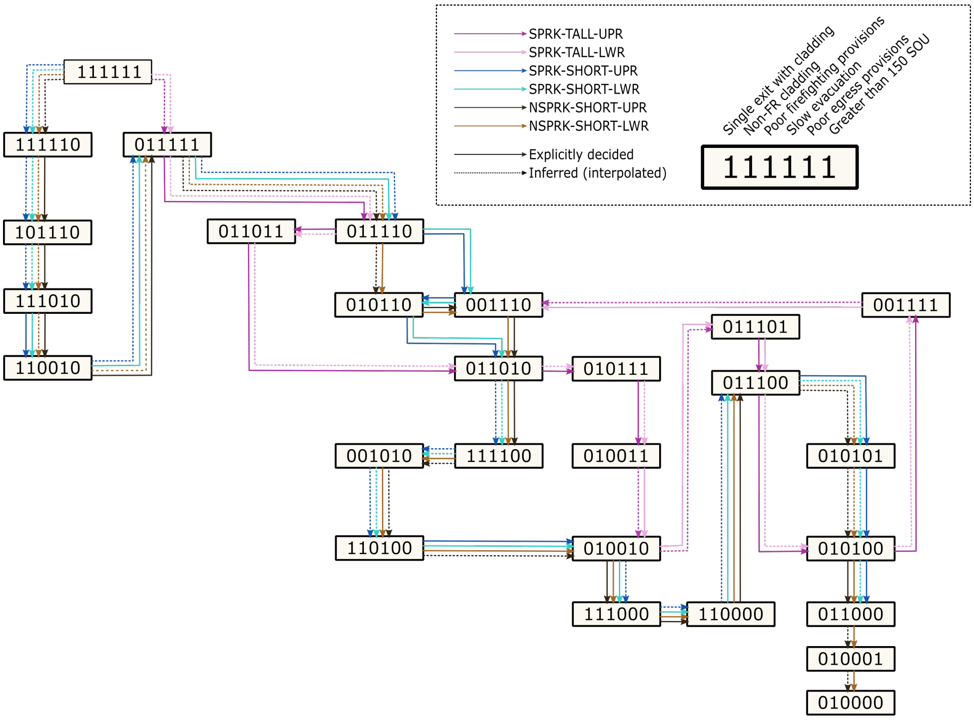



Figure C.7: Master pathways. An electronic version of Figure C.5, after changes to the ordering is made to ensure consistency.

# D Bushfire and urban vegetation fire

Early in the CRPM development the team explored ways of estimating fire threat presence and likelihood. The consideration of vegetation fires (bushfire, grassfire, and so on) was part of this.

- Outside of metropolitan Melbourne, Geelong and the Mornington Peninsula the CSV dataset has buildings with combustible cladding in Bendigo, Portland, Lakes Entrance, Paynesville, Hastings, San Remo, Anglesea, Torquay and Ocean Grove. Some of these have some potential interaction with bushfire events, while others are deep inside town centres and so are much less likely to be exposed to bushfire risk except via extreme episodes of ember attack:
  - Ocean Grove and Bendigo: these buildings in the heart of the commercial precincts.
  - Torquay, Hastings, San Remo, Portland and Paynesville: edge of commercial precinct, largely built-up area but with some nearby parkland in some cases.
  - Anglesea and Lakes Entrance: the facilities here are adjacent to coastal reserves and have non-trivial bushfire exposure.
- The building in Geelong is within the parkland and entertainment precinct, and thus including potential exposure to threats including fireworks, street food cooking, vehicle impacts and urban disturbances.
- With the exception of the building in Hastings, the Mornington Peninsula buildings are not further south than Frankston, are all in fully built-up areas, and have little if any chance of bushfire ember-attack.
- A few metropolitan buildings are proximal to parkland which might pose vegetation fire risk (in line with considerations under the current electrical safety regulations), otherwise none appear near enough to the urban fringe to have direct bushfire risks.

A building in Lakes Entrance has bushfire threat associated with ember attack coming from fires approaching from the north and west under catastrophic fire conditions, and/or from very large blazes further north in Colquhuon Regional Park. In the metro area, some buildings with combustible cladding have potential threat from fire in vegetation, this being from bushfire in the peri-urban area or from fire in significant tracts of urban parkland and reserves of various types. Pertinent case studies of urban fire to keep in mind are the Plenty Gorge fire in late 2019 [McMillan and Cunningham, 2019] and urban fringe fires on Black Saturday (Chapters 12-15 of the VBRC report [Teague et al., 2010]), each of which damaged or destroyed buildings.

With this potential in mind, a survey of the building locations noted in the RAT summary results was undertaken, and relevant buildings were noted. In building experts' view the vegetation risk threat is a special-case issue best left for case-by-case program management intervention rather than being assessed within the mainstream prioritization method.

# E RAT variable coding instructions

These are courtesy CSV in February 2021.

## E.1 Cladding Type

The highest risk type of cladding present should be selected (e.g. either ACP PE or EPS where these are present). User input for this row in the RAT tool (Row 3):

- ACP PE (a core with 30-100% polyethylene)
- ACP with an unknown core
- Expanded polystyrene cladding
- ACP with a core consisting of 30% or less polyethylene (many types of ACP FR cladding)
- ACP with a core consisting of 10% or less polyethylene (often branded as A1 or A2 type products)

## E.2 Fire fighting provisions

RAT Row 15 requires an overall score for the adequacy of fire fighting provisions. These scores should be based on an informed opinion, preferably from a representative of the relevant fire agency, of the overall adequacy of the building's fire fighting provisions. Example: combustible cladding around fire services such as boosters, and buildings with single staircases, will impede fire fighting ability. Key considerations should be suitable facilities to:

1. Coordinate fire brigade intervention during an emergency, appropriate to:
   - the function or use of the building
   - the floor area of the building, and
   - the height of the building
2. Control the development and spread of fire, usually by an automatic sprinkler system. Key factors may include:
   - the location of the nearest hydrant and whether it has a booster or pump
   - whether the fire indicator panel is in close proximity to combustible cladding
   - whether a fire control centre is required and its access is hindered by combustible cladding
   - the distance of the hardstand from the building and its accessibility for a fire truck
   - the accessibility of each face of the building for fire fighting purposes, and
   - the presence of any encumbrances such as over head power or tram wires.

## E.3 Speed of evacuation

This variable calculates an overall score for the speed of evacuation, being the time occupants take to leave the building or to enter a safe refuge such as a fire isolated stair without being subject to untenable conditions once a fire has commenced. Expert panel advice is required to adequately assess the likely speed of evacuation. Experience demonstrates that different categories of occupants are likely to evacuate a building at variable speeds. Key considerations should be:

- smoke and fire detection
- occupant warning systems
- monitored systems
- the number of storeys above ground
- the number of SOUs/occupants
- whether occupants are ambulant or need assistance
- the length of corridors, and
- the provision of safe refuges such as a fire isolated stair

## E.4 Egress provisions

RAT Row 13 considers the adequacy of egress provisions in the building. These scores should be based on an informed opinion by members of an expert panel regarding the overall adequacy of the building's egress provisions, to enable occupants to evacuate safely. This assessment should take into account the building type and use, the number and location of exits, the number and location of stairs, the adequacy of fire isolation systems, the presence of any combustible cladding around exits, the rise in storeys above ground, the type of stairs (e.g., fire isolated, non isolated, or open), the location of those stairs, and the provision of a sprinkler system.

## E.5 Number of occupants

The number of units/occupants influences the potential consequence of a severe fire and the overall ability of residents to exit the building in the event of an emergency. This assessment is based on the number of sole occupancy units (SOUs) for residential buildings, or the maximum occupancy according to the occupancy permit for other types of buildings. User Input for the relevant row (Row 2):

- 1-10 units
- 11-50 units
- 51-150 units
- 151+ units

OR

- 1-30 occupants
- 31-150 occupants
- 151-450 occupants
- 451+ occupants

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