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COST-EFFECTIVE MITIGATION STRATEGY DEVELOPMENT FOR FLOOD PRONE BUILDINGS

Preliminary Building Schema

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Contents

Executive Summary

Within Australian communities there is a wide range of building types. These vary in many attributes that include floor area, number of storeys, age, architectural style, fit out quality, construction material types and the level of maintenance. For mitigation research it is necessary to take this range of building types and geometrics and discretise it into building classes or categories of similar, if not identical, vulnerability. This “pigeon holing” strategy makes research on impact, risk and mitigation more tractable in that vulnerabilities can be assigned to each class with the reduced variability within the class captured in the uncertainty of the model. Available exposure information can also be mapped to the schema along with building types that can particularly benefit from retrofit interventions.

This report presents the preliminary building schema proposed for the Cost Effective Mitigation Strategy Development for Flood Prone Buildings BNHCRC project. The report discusses the utility of a building schema and which building attributes are important for distinguishing between houses of different vulnerabilities in the Australian building stock.

The proposed schema divides each building into the sub-elements of foundations, bottom floor, upper floors (if any) and roof to describe its vulnerability. Through this arrangement it is made possible to assess vulnerability of structures with different construction material used in different floors and also to assess vulnerability of tall structures where only bottom floors are expected to be inundated. The schema classifies each floor system based on the following attributes:

- Construction period
- Fit-out quality
- Storey height
- Bottom floor system
- Internal wall material
- External wall material

Excluding combinations that are invalid in an Australian context, the draft schema defines 60 discrete vulnerability classes based on the above mentioned attributes. Furthermore, the schema proposed 6 roof types based on material and pitch of the roof.

This proposed schema is the initial categorisation of residential structures as to vulnerability class for this project. It is expected to change and be refined as the project is taken forward and the specific building types for retrofit research are identified. The concept of “nestability” may be subsequently used where mitigation research focuses on several building types that fall within a single broader category and become sub-classes. The draft schema has been developed in recognition of the current and projected ability to define national building exposure and of the parallel BNHCRC mitigation projects examining vulnerability to earthquake and severe wind. While vulnerability schemas are hazard specific, alignment has been sought with the schemas for other hazards where possible.

1 Introduction

The Bushfire and Natural Hazards Collaborative Research Centre (BNHCRC) project entitled "Cost-effective mitigation strategy development for flood prone buildings" will examine the opportunities for reducing the vulnerability of Australian residential buildings. It will address the need for an evidence base to inform decision making on the mitigation of the flood risk posed by the most vulnerable Australian houses and complements parallel BNHCRC projects for earthquake and severe wind. This project will investigate methods for the upgrading of existing housing stock in floodplains to increase the resilience of there in future flood events. It is important that the latest research and economically optimum upgrading solutions are applied to existing houses to optimise the use of finite mitigation resources. The risk mitigation achieved will decrease human suffering, improve safety and ensure amenity for communities.

The project will make assessments of the reduction in damage loss that will ensue from the implementation of a range of mitigation measures developed by the project. This research requires the context of a building vulnerability classification, or schema. The schema takes the continuum of buildings nationally and discretises them into building classes or categories of similar, if not identical, vulnerability. This "pigeon holing" strategy makes research on mitigation more tractable in that vulnerabilities can be assigned to each class with the reduced variability within the class captured in the uncertainty of the model.

In this report, the development of building schema for flood is summarised. Several schemas for categorising buildings for flood in the literature are presented. Finally, key building attributes for assigning vulnerability to Australian residential structures are selected and a draft schema for this project is presented.

2 Objective of building schema

Building schema provide a mechanism by which vulnerability relationships are applied to individual buildings within an exposure database. That is, during a risk or impact assessment each entry in an exposure database within the study area is assigned a vulnerability curve from a limited suite of available curves. The assignation is based on the type, or *class*, of building. The class is, in turn, determined by the building attributes held within the exposure database for the building in question. Thus a building schema is a classification of the infinite variety of building forms found in the Australian housing stock into a manageable number of classes for which vulnerability relationships can be developed.

The classes identified within the schema have to represent the variety of housing within the nation's building stock and, more specifically, the variation in vulnerability across the nation's building stock. There is little value in including classes that may exist elsewhere but are rare in the Australian building stock. Furthermore, the schema must identify specific housing classes for which the project develops mitigation strategies.

The schema proposed herein utilises on few of building attributes which are currently held within Geoscience Australia's exposure database, National Exposure Information System (NEXIS). However, research undertaken during the project points to other building attributes, not yet captured by NEXIS, that distinguish between classes of buildings with significantly different vulnerabilities.

3 Background to the vulnerability of housing to flood

The design and construction of housing in Australia is regulated by the National Construction Code (NCC) of which Volumes 1 and 2 are the Building Code of Australia (BCA) and its State–specific Appendices. The BCA was first published in 1988 and has undergone many revisions since that year. It, and the Australian Standards referenced therein, represent the culmination of a long evolution of building standards in Australia.

While there is a construction standard issued by the Australian Building Code Board (ABCB, 2012) for new construction in flood prone areas, almost all of the existing building stock in flood prone areas has not benefitted from it. Many communities on those flood plains have been inundated during past flood events. This has resulted in significant logistical challenges for emergency management with damage costs and disruption to communities. It has further resulted in considerable cost to all levels of government to repair damage and enable community recovery.

Recent events in Queensland in 2011 and 2013 have highlighted the vulnerability of housing to flooding and have caused billions of dollars in losses. Geoscience Australia conducted a number of post-disaster surveys to assess building damage due to flood inundation. The surveys consisted of a capture of street view images to obtain an overview of the damage within the flood extents (see Figure 3.1); foot surveys to capture detailed building attributes and damage incurred; and postal surveys to assess building repair costs and social consequences due to floods.

To reduce future losses there is a significant need for mitigating the risk posed by existing buildings in flood prone areas. Therefore, this project aims to provide an evidence base to inform decision making on the mitigation of flood risk by providing information on the cost-effectiveness of a range of mitigation strategies involving alterations to existing residential buildings.

Figure 3.1 Building damage recorded during field surveys conducted after 2011Southeast Queensland flood by Geoscience Australia

4 Existing Building Schemas

Many different building schemas have been developed internationally for a range of uses within different projects e.g. HAZUS, UNISDR GAR, GMMA RAP, RiskScape. As a schema is applied to greater extents of asset exposure which encompass more variations in building typology, hazard magnitude and building regulations, additional building classes must be added to capture the variation in vulnerability present. A few examples of building schemas developed internationally are discussed below.

United Nations' Global Assessment of Risk: Global

Geoscience Australia hosted a workshop during November, 2013 to develop regional heuristic vulnerability curves for incorporation into the United Nations' Global Assessment of Risk (GAR15). The workshop considered the vulnerability of buildings in the Asia-Pacific region to five hazards of which flood was one. During the flood sub-workshop a building schema with enhanced detail was developed from the overall GAR15 building schema in an effort to capture the variety of buildings found within the region (Maqsood et al. 2014). An extract of the schema is shown in Table 4.1. The extract captures the building classes relevant to houses. Some of the classes are not well represented in the Australian housing inventory, for example, pole and beam construction and adobe. In this schema the variation of vulnerability within a given class of building is captured by the concept of 'water susceptible materials, type of finishes, floor system and number of storeys'.

Table 4.1 Extract of building schema developed at the GAR15 Regional Vulnerability Workshop. The dark shaded cells are those classes that are considered not to exist (Maqsood et al. 2014).

Workshop Label	Description	Storeys	Residential Building usage	Industrial Building usage	Commercial Building usage
W1-NE	Wood, Light Frame (≤5,000 sq. ft.) non-elevated	1			
W1-E	Wood, Light Frame (≤5,000 sq. ft.) elevated	1			
PB	Pole and beam structure	1			
W1	Wood, Light Frame (≤5,000 sq. ft.)	2			
W2	Wood, Commercial and Industrial (>5,000 sq. ft.)	1			
S3	Steel Light Frame	1			
C3L-1-NS	Concrete Frame with non-susceptible interior walls	1			
C3L-1-S	Concrete Frame with susceptible interior walls	1			
C3L-2-NS	Concrete Frame with non-susceptible interior walls	2			
C3L-2-S	Concrete Frame with susceptible interior walls	2			
C3L-3-NS	Concrete Frame with non-susceptible interior walls	3			
C3L-3-S	Concrete Frame with susceptible interior walls	3			
AD1L	Adobe	1			

The GAR15 schema for flood comprises 27 building classes as set out in Table 4.1. The schema was developed within two constraints: firstly, the lack of validation data within the region making any attempt to develop vulnerability curves for a more detailed schema problematic; and, secondly, the need for the building classes described by the schema to be identifiable by the exposure database. It eventuated that the exposure database could not identify the housing stock to the level of detail in the building schema and several classes were combined to an even coarser schema (that was common across hazards) for the purposes of the risk assessment.

HAZUS-MH: United States of America

United States' Federal Emergency management Agency (FEMA) has developed a software package for natural hazard loss estimation called HAZUS-MH. The model is based on GIS technology and it can simulate losses for four hazard types i.e. earthquake, flood, hurricanes and coastal surges (FEMA, 2007). The HAZUS-MH flood model is intended to be used by floodplain managers to make informed decision regarding land use and flood risk management. HAZUS-MH classifies building stock on the basis of these building attributes: Structural System (5 types) and Storey Class (3 types). Table 4.2 presents the broader building schema used in HAZUS-MH. Stage-damage functions or flood vulnerability curves are sourced by HAZUS-MH from Federal Insurance Administration (FIA) and U.S. Army Corps of Engineers (USACE) to be used for loss assessment.

Table 4.2 Extract of building schema developed by HAZUS (FEMA, 2007).

Structural System	Description	Storey Class	Storeys
Wood	Wood light frame		All
Steel	Steel frame structures including those with infill walls and concrete shear walls	Low-rise	1-3
		Mid-rise	4-7
		High-rise	8+
Concrete	Concrete frame or shear walls structures including tilt-up, precast and infill walls	Low-rise	1-3
		Mid-rise	4-7
		High-rise	8+
Masonry	All structures with masonry bearing walls	Low-rise	1-3
		Mid-rise	4-7
		High-rise	8+
MH	Mobile homes		All

RiskScape: New Zealand

RiskScape is a joint venture between the New Zealand National Institute of Water and Atmospheric Research (NIWA) and GNS Science. It is a tool for analysing risks and impacts from five natural hazards i.e. earthquake, flood, tsunami, volcanic ash and windstorm (RiskScape, 2010). It provides detailed building attributes to classify the New Zealand building stock. The classification depends on the building attributes as enlisted in Table 4.3.

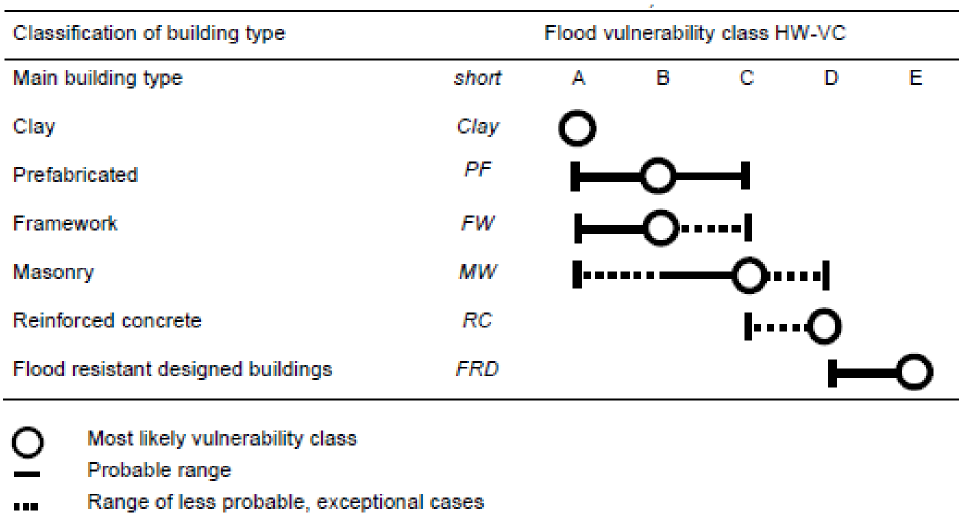
Table 4.3 Extract of building attributes utilised by RiskScape for definig vulnerability classes (RiskScape, 2010).

Attributes	Construction Type	Wall Cladding	Roof Cladding
Construction Type	Reinforced Concrete Shear Wall	Weatherboard	Clay/Concrete Tile
Deprivation Index	Reinforced Concrete Moment Resisting Frame	Roughcast	Concrete Slab
Floor Area	Steel Braced Frame	Stucco	Metal Tile
Floor Height	Steel Moment Resisting Frame	Corrugated Iron	Sheet Metal
Footprint Area	Light Timber	Fibre Cement Sheet	Other
Occupancy	Tilt Up Panel	Fibre Cement Plank	
Replacement Cost	Light Industrial	Reinforced Concrete	
Roof Cladding Class	Brick Masonry	Concrete Masonry	
Roof Pitch	Concrete Masonry	Brick Masonry	
Storeys	Other	Glass	
Use Category		Curtain Wall Glazing	
Wall Cladding Class		Sheet Metal	
Year of Construction		Other	

Earthquake Damage Analysis Center: Germany

Schwarz and Maiwald (2008) adopted the concept of the European Macroseismic Scale-1998 (Grünthal et al. 1998) to classify the building types for flood vulnerability. Based on the research on several floods in Germany (2002, 2005 and 2006) they developed the most likely vulnerability classes for 7 building types with probable and less probable ranges. Table 4.4 presents the building type classification and typical flood vulnerability classes for the German building stock. Five Flood Vulnerability Classes (HW-A to HW-E) were identified covering a range from low resistance or high vulnerability (HW-A) to a flood resistant class (HW-E).

Table 4.4 Classification of building types and vulnerability classes (Schwarz and Maiwald, 2008).



Greater Metro Manila Area Risk Assessment Project: Philippines

Within the Greater Metro Manila Risk Assessment Project, Pacheco et al. 2013 developed a building schema for flood vulnerability and risk assessment in the Metro Manila area in the Philippines (see Table 4.5). The schema was adapted from the HAZUS's earthquake schema and is tailored for flood hazard and predominant building types in the Metro Manila. The schema classified the building stock by building material and number of storeys. A separate class was assigned for one and two storey buildings within some building types to differentiate the level of exposure for a certain flood event.

Table 4.5 Classification of building types for the Greater Metro Manila Area (Pacheco et al., 2013).

Building Material	Building Type	Description	Building Type Code	Storeys
Wood	W1	Wood light frame	W1-L-1	1
			W1-L-1	2
	W3	Bamboo	W3L	Low-rise
	N	Makeshift	N-L-1	1
			N-L-2	2
Masonry	MWS	Concrete hollow blocks with wood or light metal	MWS-L	Low-rise
	CHB	Concrete hollow blocks	CHB-L-1	1
			CHB-L-2	2
Concrete	CWS	Reinforced concrete moment frames with wood or light metal	CWS-L	Low-rise
	C1	Reinforced concrete moment frames	C1-L-1	1
			C1-L-2	2
			C1-M	Mid-rise
Steel	S1	Steel moment frames	S1-L-1	1
			S1-L-2	2
			S1-M	Mid-rise

NSW-OEH: Australia

New South Wales Office of Environment and Heritage (NSW-OEH) in Australia produced a guideline to assess building damage cost for residential structures within the state of New South Wales (Mcluckie, 2007). Three types of residential structures were selected and stage-damage curves were produced. The structures were:

- Single storey slab-on-grade/Low-set residential
- Single storey high-set residential
- Two storey residential

Geoscience Australia: Australia

After 2011 Queensland floods, Geoscience Australia conducted damage surveys to record damage to residential buildings. The data captured during the surveys facilitated the development of a building schema for flood damage assessment. A building schema with 11 generic building types was developed by Wehner et al. (2012) by considering several key building attributes such as bottom floor system, number of storeys, external wall material, internal wall material and the presence of garage. The building schema was extended (see Table 4.6) in another project in the Alexandra Canal Catchment area in South Sydney by including Victorian terrace houses and non-residential buildings to encompass/include the local building stock (Maqsood et al. 2013).

Table 4.6 Classification of building types in southeast Queensland and Sydney (Maqsood et al. 2013).

Region	Costing Module	Building Type	Description
Sydney	ACFS1a	Residential: Victorian terrace	1 storey, without basement
Sydney	ACFS1b	Residential: Victorian terrace	1 storey, with basement
Sydney	ACFS2a	Residential: Victorian terrace	2 storey, without basement
Sydney	ACFS2b	Residential: Victorian terrace	2 storey, with basement
Sydney	ACFS3	Mixed use: retail/residential	1 storey, without basement
Sydney	ACFS4	Commercial: Showroom/Office	2 storey, without basement
Sydney	ACFS5	Commercial: Warehouse/Garage	2 storey, without basement
Sydney	ACFS6	Industrial: Factory	1 storey, without basement
South-east Queensland	FCM1	Residential	1 storey, Raised Floor, Weatherboard or panel cladding, no garage, Hardboard lining
South-east Queensland	FCM2	Residential	1 storey, Raised Floor, Weatherboard or panel cladding, no garage, timber lining
South-east Queensland	FCM3	Residential	2 storey, Slab-on-Grade, Cavity Masonry lower storey, Weatherboard upper storey, metal roof, no garage, Plasterboard lining
South-east Queensland	FCM4	Residential	2 storey, Slab-on-Grade, Cavity Masonry lower storey, Weatherboard upper storey, metal roof, garage, Plasterboard lining
South-east Queensland	FCM5	Residential	2 storey, Slab-on-Grade, Weatherboard cladding, partial lower floor, Plasterboard lining
South-east Queensland	FCM6	Residential	2 storey, Raised Floor, Weatherboard cladding, no garage, v lining
South-east Queensland	FCM7	Residential	1 storey, Slab-on-Grade, Brick Veneer, garage, Plasterboard lining
South-east Queensland	FCM8	Residential	1 storey, Slab-on-Grade, Brick Veneer, no garage, Plasterboard lining
South-east Queensland	FCM9	Residential	1 storey, Raised Floor, Brick Veneer, no garage, Plasterboard lining
South-east Queensland	FCM10	Residential	1 storey, Slab-on-Grade, Cavity Masonry, no garage
South-east	FCM11	Residential	1 storey, Raised Floor, Cavity Masonry, no garage

5 Proposed Schema

While an almost infinite range of individual housing forms are found in Australian communities, these are categorised into a limited number of types based on the housing features that influence vulnerability to flood. This work draws upon post-disaster damage survey results recorded by Geoscience Australia and data contained in Geoscience Australia's National Exposure Information System (NEXIS).

The aim of this project is to develop cost effective mitigation strategies to improve the vulnerability of Australian housing exposed to flood hazard. As discussed in Section 2, post-disaster damage survey activity has identified that the severity of damage is strongly influenced by the nature of bottom floor construction and internal wall construction. Thus it is anticipated that the project's research will focus on at least these aspects of built environment. Hence, the building schema must distinguish, at a minimum, between houses with different floor types and external wall materials to establish what proportion of the housing stock within a study area may benefit from the mitigation strategies developed by the project. Other attributes that are known to affect a house's vulnerability to flood are considered to be building age, fit-out quality, storey height and internal wall material.

Moreover, the schema should also differentiate between buildings with different construction material used in floor systems. Therefore, in the proposed schema there is a fundamental shift from describing the building to one that focuses on sub-componnets. In turn, there is a corresponding change in the way to assess building vulnerability and potential losses in flood events. In this new approach the schema divides a building into its main components i.e. substructure and superstructure. The superstructure is divided into ground floor, upper floors (if any) and roof (see Figure 5.1). Each floor is then classified by identifying the below mentioned six attributes.

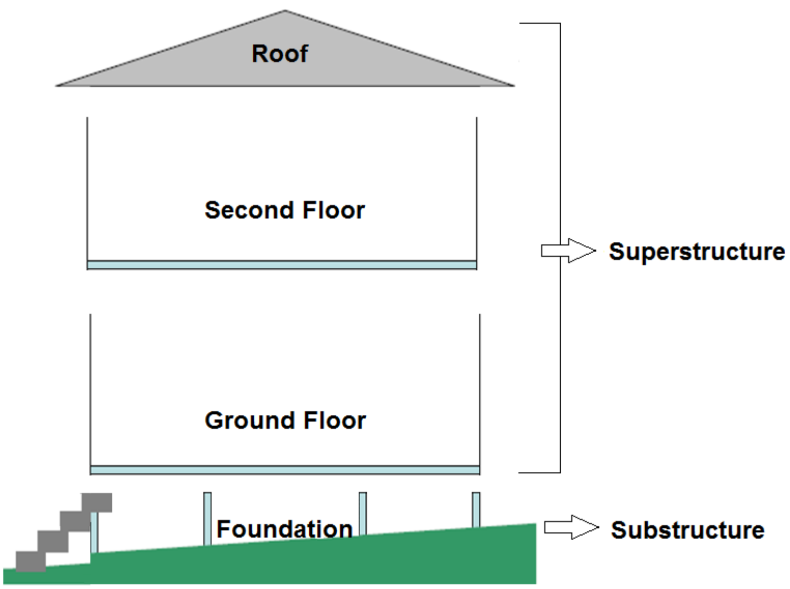


Figure 5.1 Building structure divided into main components

The proposed schema is set out in Table 5.1 which utilises the following six key attributes:

- Building age (construction period)
- Fit-out quality
- Storey height
- Bottom floor system
- Internal wall material and
- External wall material

Table 5.1 Proposed building storey type schema for flood hazard. The dark shaded cells are those thought to be poorly represented in the Australian building stock.

Construction Period	Fit out Quality	Storey Height (m)	Floor Type	Internal Wall Material	External Wall Material		
					Brick Veneer	Weather-board / Timber / Fibro	Solid Brick / Cavity Brick / Concrete
Pre 1960	Standard	2.7	Slab-on-grade	Masonry			
				Plasterboard / Hard Board			
				Timber			
			Raised: T&G Timber	Masonry			
				Plasterboard / Hard Board			
				Timber			
		3.0	Slab-on-grade	Masonry			
				Plasterboard / Hard Board			
				Timber			
			Raised: T&G Timber	Masonry			
				Plasterboard / Hard Board			
				Timber			
	Low	2.7	Slab-on-grade	Masonry			
				Plasterboard / Hard Board			
				Timber			
			Raised: T&G Timber	Masonry			
				Plasterboard / Hard Board			
				Timber			
		3.0	Slab-on-grade	Masonry			
				Plasterboard / Hard Board			
				Timber			
			Raised: T&G Timber	Masonry			
				Plasterboard / Hard Board			
				Timber			

Construction Period	Fit out Quality	Storey Height (m)	Floor Type	Internal Wall Material	External Wall Material		
					Brick Veneer	Weather-board / Timber / Fibro	Solid Brick / Cavity Brick / Concrete
Post 1960	Standard	2.4	Slab-on-grade	Masonry	■	■	
				Plasterboard / Hard Board			■
			Raised: T&G Timber	Masonry	■	■	
				Plasterboard / Hard Board			■
			Raised: Chipboard	Masonry	■	■	
				Plasterboard / Hard Board			■
		2.7	Slab-on-grade	Masonry	■	■	
				Plasterboard / Hard Board			■
			Raised: T&G Timber	Masonry	■	■	
				Plasterboard / Hard Board			■
			Raised: Chipboard	Masonry	■	■	
				Plasterboard / Hard Board			■
	Low	2.4	Slab-on-grade	Masonry	■	■	
				Plasterboard / Hard Board			■
			Raised: T&G Timber	Masonry	■	■	
				Plasterboard / Hard Board			■
			Raised: Chipboard	Masonry	■	■	
				Plasterboard / Hard Board			■
		2.7	Slab-on-grade	Masonry	■	■	
				Plasterboard / Hard Board			■
			Raised: T&G Timber	Masonry	■	■	
				Plasterboard / Hard Board			■
			Raised: Chipboard	Masonry	■	■	
				Plasterboard / Hard Board			■

The roof sub-component is classified by construction material and pitch (or slope). The roof material can be either concrete tile or metal sheet and pitch can be either low (typically less than 8 degree), medium (typically between 17 to 25 degree) or high (typically between 35 to 45 degree). Table 5.2 summarises the roof types.

Table 5.2 Proposed roof type schema for flood hazard

	Material	Pitch
Roof	Concrete tile	Low
		Medium
		High
	Metal sheet	Low
		Medium
		High

The proposed schema contains 60 possible combinations of the 6 building attributes for each floor system. The schema also proposes 6 classifications for roof depending upon material and pitch. From these a limited suite will be selected for this research representing those contributing most to community flood risk through their vulnerability and predominance.

Only a few attributes used in the schema to classify houses, such as building age and external wall material, are held within NEXIS at present. Therefore there is a need to augment NEXIS to capture more building attributes such as storey height, internal wall material, fit-out quality, floor type and roof pitch.

6 Summary

The risk posed by flood hazard to housing in Australia is disproportionally influenced by legacy housing. The development of a building schema which categorises the Australian housing stock into classes with distinctive vulnerabilities is an integral part of the risk and impact assessment process. The schema must capture the wide range of housing types extant in the country together with the variation in vulnerabilities observed in outwardly similar houses.

The proposed schema divides each building into its main components i.e. foundation, bottom floor, upper floors (if they exist) and roof. It is proposed to develop vulnerability knowledge for each of these building components separately to make possible vulnerability assessment of buildings with mixed construction material at different floor levels. The approach facilitates the development of vulnerability curves for taller buildings, buildings with basements, and buildings with mixed usages.

The schema categorises each floor level by the building attributes: Construction Period, Fit-out Quality, Storey Height, Internal Wall Material and External Wall Material. Currently, only a few these attributes are recorded within Geoscience Australia's exposure database, NEXIS, thus requiring future development in NEXIS to capture the missing attributes.

As the project progresses it is expected that the results of the research will drive modifications to the schema proposed herein. The research may indicate little or no variation in vulnerability between some proposed classes thus enabling the combining of two or more classes in the schema. Conversely the research may identify different types of buildings within a single class in the proposed schema that demonstrate significantly different vulnerabilities. This would necessitate an expansion of the proposed schema, and, possibly, the capture of further building attributes into the exposure database to enable the new house classes to be identified within the Australian housing stock.

Furthermore, the research will examine the population of houses across Australia that fall into the various classes. Some classes may be so poorly represented that they may be removed from the schema.

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