Author/s:
Paton-Cole, V;Crawford, R;Turnbull, R;Fitzgerald, E;Michalewicz, A;Garber, J

Title:
Trends in Residential Building Materials in the State of Victoria

Date:
2022

Citation:
Paton-Cole, V., Crawford, R., Turnbull, R., Fitzgerald, E., Michalewicz, A. & Garber, J. (2022). Trends in Residential Building Materials in the State of Victoria. IOP Conference Series: Earth and Environmental Science, 1101, (4), pp.042022-042022. IOP Publishing Ltd. https://doi.org/10.1088/1755-1315/1101/4/042022.

Persistent Link:
https://hdl.handle.net/11343/324779

Trends in Residential Building Materials in the State of Victoria

V Paton-Cole[1], R H Crawford[1], R Turnbull[2], E Fitzgerald[2], A Michalewicz[2] and J Garber[2]

[1]Faculty of Architecture, Building and Planning, The University of Melbourne, Parkville, VIC, 3010, Australia

[2]Melbourne Data Analytics Platform, The University of Melbourne, Parkville, VIC, 3010, Australia

vidalpc@unimelb.edu.au

Abstract. As the population in Victoria continues to grow, there has been a corresponding increase in building approvals across the State. Houses characterised as low-rise residential buildings often take the largest share of these approvals, with incessant residential building activities being driven by record low interest rates. Low-rise residential buildings comprise various building forms that use a number of specified construction materials to construct the building envelope and other structural and non-structural elements. As materials used for constructing residential building envelopes continue to evolve, these materials must be fit for purpose, and satisfy design criteria and performance requirements, while being aesthetically pleasing. This research analyses the trend in construction materials used in building envelopes of low-rise residential buildings using data from building permits issued between 1996 to 2019. The trend analysis shows that traditional double brick wall systems and suspended timber floors have reduced in popularity for houses built in the 21st century. The analysis also shows that brick veneer wall cladding systems built over slab-on-ground footings is the dominant construction form while the roof cladding material is influenced by geographical location. Insights from the data analysis indicate very little innovation has emerged in materials for residential building envelopes despite its crucial role in providing thermal comfort for inhabitants. Results from this research will serve as a basis to provide quantitative assessment of the trend in materials resource; provide insights about the impact of new building envelope products on existing industries; and perspectives on materials for future building envelopes.

1. Introduction

Residential building works constitutes a significant percentage of the total value of the building works undertaken nationally in Australia. According to the Australian Bureau of Statistics (ABS), the proportion of the total value of residential building activities amounts to about 67% of total building works [1] which includes residential and non-residential buildings, and makes significant contribution to the Australian economy. According to reports by the Housing Industry Association (HIA), the aggregate of the residential industry's direct contribution to the Australian economy is over $150 billion per annum [2]. As reported by the ABS, housing data shows that a significant proportion of residential building construction activities are carried out in the State of Victoria [3]. The value of building work and building approvals in Victoria is at an all-time high. Despite the disruption to the supply chain, shutdowns, and border closures due to COVID-19, demand for residential buildings in Victoria continue to soar. Data reported by the ABS shows that 230,578 building approvals were issued across states and territories in Australia for new residential dwellings between October 2020 and September 2021 [3]. The majority of the referred building approvals were in Victoria, with a total of 69,278 new residential dwellings approved, representing about one third of the total new dwellings. Such significant demand for new residential housing represents a gigantic amount of materials that translates to a huge proportion of non-renewable natural resources required to deliver these residential dwellings. Generally, total building approvals include the construction of new buildings; alterations and additions to existing buildings; and approved non-structural renovation and refurbishment work. Aggregating all building approvals therefore represents a remarkable amount of required construction materials, huge production of waste and emission of greenhouse gases.

In conjunction with current projections, it is expected that the population of Victoria will be 7.7 million by 2031 and a further 2.4 million people by 2051 [4], thereby growing the population to 10.1 million in the next three decades. This increase in the state's current population will be translated into significant demand for residential buildings. Notwithstanding, as residential buildings contribute significantly to the depletion of global resources and emission of waste and greenhouse gas (GHG) emissions, it is imperative that materials used in the construction of brand-new houses or for refurbishment of existing building stock be sufficiently durable to last the intended design life of buildings, thereby preserving non-renewable resources as much as possible. Residential buildings, especially standalone detached houses and horizontally attached houses (town houses) regarded as low-rise residential buildings and classified as Class 1 in the National Construction Code (NCC), are more commonly built across major capital cities in Australia. As a result, this category of residential houses in aggregate has an enormous environmental impact because of the huge volume of materials required to construct the building envelope which constitute the footings elements, walls and window framing and roof framing. Materials used for constructing residential buildings can vary across Australia, with material selection often informed by local design requirements. In the state of Victoria, materials used for constructing residential buildings has evolved significantly over time. Data and information relating to the changes in building material usage for the construction of residential buildings is however sparsely available.

This research aims to analyse the historical trends in materials used for constructing the envelopes of residential buildings in the State of Victoria and identify correlation between geographical dispersion. With scarcity of information and data around trend in materials being used for residential buildings, this research therefore fills a gap in knowledge about changes to building materials and their usage in residential buildings. It is expected that results from this study will provide quantitative assessment of materials resource for residential buildings built in Victoria and help inform policy towards a more sustainable form of construction in the future.

The structure of this paper is as follows: The first section provides a background on residential buildings and materials while the second section provides an overview of code requirements for construction materials. The third section presents data collection methods followed by findings and discussion in the fourth and finally conclusions and opportunities for future research.

2. Code requirements for materials used in residential buildings

Materials used for constructing residential buildings must be compliant with the purpose they are specified, approved, and used for. This responsibility applies to all industry stakeholders that have an involvement in the manufacture or supply of building materials, and the design, approval, and construction of residential buildings. Post incident analyses in Victoria have indicated the issue of non-compliant use of building materials and non-compliant building materials in the building supply chain.

In Australia, the National Construction Code (NCC) provides a set of technical design requirements and construction provisions, prescribing the minimum required level for the safety, health, amenity, accessibility and sustainability in the design and construction of new buildings (and new building work in existing buildings) [5]. Provisions in the code include compliance requirements covering matters such as structure, fire resistance, access and egress, services and equipment, and energy efficiency. These fundamental provisions in the code thereby provide the framework for the materials needed for constructing the systems and sub-systems in various forms of residential buildings, while ensuring that proposed buildings are fit for their intended purpose. As the NCC does not contain details of design and construction requirements, it calls upon other reference documents such as Australian Standards which provide the basis for the material design used for the construction of the various systems and sub-systems in residential buildings. In Victoria, most materials used in constructing Class 1 and Class 2 buildings [5] as per the NCC must comply with minimum design requirements set out in the relevant Australian Standard [6-9].

Most of the construction materials used for constructing residential buildings will be built into the building envelope. The National Construction Code [5] defines the "building envelope as the parts of a building fabric that separate artificially heated or cooled spaces from (i) the exterior of the building; or (ii) other spaces that are not artificially heated or cooled" whereas "fabric represents the building structural elements and components of a building including the roof, ceilings, walls, glazing and floors". This means that materials used for constructing the envelope in residential buildings must be sufficiently durable to withstand the elements. Materials used for framing the building envelope are required to be structurally reliable so as to withstand the combination of loads and other actions to which the building may be reasonably subjected while glazed elements must be installed to avoid undue risk of injury to occupants. The residential building envelope must also be constructed to provide resistance to moisture from the outside and rising moisture from the ground. A functional characteristic of materials used in residential buildings is to limit the spread of fire in between adjacent structures in Class 1 buildings or between sole occupancy units in Class 2 buildings. Other performance requirements of materials used for framing residential building envelopes include energy efficiency and thermal and sound insulation characteristics.

In Victoria, verification of compliance requirements for materials used in both Class 1 and Class 2 residential building has not always been undertaken and has led to poor performance of residential buildings [10] as well as devastating consequences in multi-storey buildings [11] with combustible cladding [12]. A recent audit of external wall cladding materials used in Classes 2, 3 and 9 buildings across the State of Victoria was undertaken by a cladding task force [13]. This was commissioned by the Victorian State Government to audit the extent of non-compliant wall cladding on buildings. The report revealed that out of 1369 buildings surveyed, over 50% were referred to an expert panel for further determination while 44 of these were placed in a higher risk category. It was reported that the majority of the high risk buildings were two or three storeys high [13] having a single exit and inadequate fire safety measures. With the evolution of advanced materials available for the construction of these residential buildings, it is therefore reasonable to conclude that there exists a non-compliance concern and a gap in regulatory requirements.

Non-compliance of building materials leading to poor performance of residential buildings during operations is not unique to Victoria or Australia. There have been recurrent issues associated with poor performance of materials in New South Wales and Queensland [14], with similar incidences reported overseas in the UK [15], China [16, 17] and Dubai [18, 19].

2.1. Review of materials used in the building envelope
This section presents a review of some of the materials used in the systems and sub-systems of the building envelope in residential buildings, thereby providing an insight into how the building envelope has evolved. Until 2011, the ABS collected statistics relating to the number of dwellings built stratified by common building materials and structural framing use [20]. Such data ceased to be published due to concern around

the quality of data. There have been very limited attempts to examine the trend in materials used in constructing residential building work and no significant analysis of the determinants of material choice. Notwithstanding, the following section presents a succinct description of materials used in framing the ground floor (substructure), and wall and roof (superstructure).

2.1.1. Ground floor framing. Materials used for framing the ground floor that interacts with the ground is often influenced by the class of building and apparent soil conditions. Floors in Class 1 buildings which constitute low-rise buildings (1–2 storeys high) are commonly framed as a slab on ground using concrete or alternatively framed as a suspended floor [7]. Often site topography will dictate the feasibility of the choice of footing in order to achieve an economic design. Class 2 buildings (walk up flats and apartments) will often be built on a concrete footing and depending on the height of the building will have a deep footing and a basement. Regardless of the building class, the footing system must also be capable to limit the transfer of thermal energy and infiltration of moisture into habitable spaces. Over the years, very little has changed around the framing of footing systems for residential buildings.

2.1.2. Wall framing and cladding. Utilisation of materials for wall construction in residential buildings has evolved from traditional solid masonry structures with thicker walls that rely on its selfweight for stability; to reinforced concrete frames with unreinforced masonry infill panels used in “walk-up” apartment buildings [21]; and lightweight wall framing using brick veneer [22], weatherboard, fibre cement sheet or expanded polystyrene as cladding materials. Timber and cold formed steel are the most common wall framing materials used in low-rise residential building with the aforementioned cladding options while high density materials such as concrete are used in Class 2 buildings. The choice of materials for the wall framing and cladding is influenced by a variety of factors including building class, geometry, typology and climatic zone to ensure that the wall assemblage inclusive of glazed penetrations performs effectively and satisfies its intended functions, since the wall elements will constitute most of the building envelope that interacts with the elements. Fundamentally, the materials used in constructing the wall assembly must be capable of providing thermal comfort within the building and adequate to manage vapour pressure, condensation and mould [23]. The NCC makes provision for energy efficiency and to ensure perfomance requirements are satisfied: an “R-value” rating is used to measure the thermal resistance of the walls based on the termal conductivity of the individual layers used to form the wall units. Many Australian studies have been undertaken to understand thermal performance of residential buildings [24-26] while others [27, 28] have investigated the relationship between life cycle energy and service life of materials used in buildings.

2.1.3. Roof framing and cladding. Materials used for roof framing in residential buildings can be either timber or cold formed steel often fabricated in the form of trusses to form the roof structure. Generally the roof structure is informed by the roof cladding., with steel sheeting or roof tiles being the most common across most residential buildings in Victoria. The roof framing system plays an important role in thermal comfort and must therefore comply to the R-value criteria prescribed in the NCC [5]. Despite its role as part of the building envelope, very little research has been undertaken to improve performance of materials used in roof cladding. Some studies have been undertaken to understand the benefits of green roofs in Australia [29, 30] with its potential to reduce heating and cooling requirements and thereby decreasing the lifecycle energy.

3. Research approach

This section describes the systematic approach adopted in collecting, processing and analysing the data on building materials used for constructing the envelope for residential buildings in the State of Victoria, Australia.

3.1. Data collection

In most cases, residential buildings that are newly built, renovated or retrofitted need to obtain a building permit prior to commencement of construction. The Building Act and Building Regulations for Victoria outline requirements to ensure building design accords with compliance. At the time when the building permit application is initiated, a catalogue of materials to be used for the construction of the building envelope will need to be appended to enable the relevant building surveyor (RBS) check for suitability of the proposed materials prior to issuance of the permit. The Victorian Building Authority (VBA) requires that only building materials that are compliant for the use are specified, approved and used in the construction of a building. As the (VBA) is the responsible regulator for the building industry in Victoria, building permits issued either by municipal or private building surveyors must be reported to the industry regulator. The data reported includes separate fields indicating the wall, floor, frame, and roof materials for every project in Victoria that requires a building permit. Such permit data acquired for residential buildings from 1996 to 2019 was used in this research. It should be noted that other relevant information about individual projects is also collected at the building permit application stage and includes geolocation, build cost, and allotment area amongst others.

3.2. Data processing

The data from the VBA came in a structured format, however still required extensive cleaning to be useful for this and future analyses. The data collated by the VBA had been gathered from the seventy-nine local government areas over a period of twenty years, and as such there was a wide variety in the style and formatting of the data. For geocoding, we used the AURIN Data61-GNAF Geocoder, built and made available by the Australian Urban Research Infrastructure Network (AURIN) using address and coordinate data made available by the Australian Commonwealth Government in the Geoscape Geocoded National Address File (G-NAF). The geocoder requires addresses to be ordered correctly and extraneous information removed to correctly geolocate the address, necessitating detailed data cleaning for the most accurate results. This included standardising formatting, particularly case, spacing, blank values, spelling, punctuation and location names. New columns were inserted to capture additional or incorrect data included in the lot number, street number, street, suburb, and postcode columns, and for the geocoded addresses and co-ordinates, and address details in the wrong columns were corrected. The data was filtered and moved using the Pandas.loc method and regular expressions. This needed to be done iteratively to account for the different delimitators and other formatting choices made when the data was entered. The G-NAF, AURIN Data61-GNAF Geocoder web interface, and Google Maps were used to check individual address details while cleaning. In total, 685,313 of the 1,454,312 rows were changed during this process (approx. 47%). In total, 1,028,400 unique addresses were geocoded, and a new parquet file was created with the clean data, including co-ordinates, which was used for the analysis.

3.3. Data analysis

Based on the above basis, the historical trend of materials used in residential buildings were analysed. Results from the data analysis are described in the following section in which the various materials used in Class 1 and Class 2 buildings are presented. Only private sector building permits issued between 1996 to 2019 were included and the application of such filters reduced the dataset to a total of 865,297 permits. Details include quantitative analysis of the distribution of different materials used in the building envelope in new, renovated and retrofitted buildings, their geographical distribution, proportion of buildings with common floor, wall and roof systems and a correlational analysis with the number of floor levels, project cost and total floor area.

4. Findings and discussion

This section succinctly presents findings of the data analysis and a discussion of the results.

4.1. Distribution of materials in residential building envelopes

Table 1 shows the annual tally of residential building permit applications and the distribution of materials used in the envelopes of residential buildings built in Victoria between 1996 to 2019. The reported annual total is grouped by calendar year of permit application as shown in Figure 1. Data shows that concrete material with traditional slab on ground remains the most popular form of floor framing, accounting for about 60% (on average) of floors in residential buildings. On the other hand, timber floor framing which was popular with suspended floor framing has become significantly unpopular, representing about 28% of residential framing systems in 1997 to less than 10% of floor framing since 2013. Concrete floor framing has a perceived warmth and comfort and would be a preferred choice to many. Due to its solid geometry, concrete slab on ground can provide a more stable and robust substructure in repelling the elements and dealing with changes in the foundation that could lead to distress in the superstructure. As majority of residential houses across Victoria are built on a flat terrain, the use of suspended timber floor framing is not appropriate. Timber floor framing are often stick built, they are labour intensive to construct, and its geometric form means it requires regular maintenance which could be costly when compared to slab on ground.

Wall framing using timber remains the most popular means of constructing residential houses, with an increase from about 55% in 1996 to 86% in 2019 while wall framing with steel remains unpopular. Depending on the contract arrangement, the building designer, architect or builders are typically responsible for nominating the materials used for the wall framing, that will also serve as the load bearing structure for the building. In Victoria, many building designers, architect and builders are trained to design and/or build with timber and most will therefore nominate timber wall framing to their clients. This further explains the average annual distribution of frame material in Figure 1, with about two-thirds of residential houses framed with timber material. Subsequently, most carpenters are trained to build with timber and the inherent risk of non-conformance is reduced by building with timber wall framing. Familiarity with the timber material can be translated to reliability and implicitly lower labour cost as well as reduced maintenance costs.

Similarly, analysis of results shows that brick veneer remains the most popular cladding form and could be largely attributed to its aesthetic appeal, low maintenance and familiarity with bricklayers. Double brick walls that was popularly used in the past has dwindled to less than 1% over the last decade. This could be attributed to the higher labour hours required for constructing double brick walls that could be translated to increased costs. Data analysis shows that alternative wall cladding materials classified in the “other” category were popularly used during the early 2000s. This could be attributed to the national skill shortages of bricklayers during the same period.

It should be noted that the “others” category represents all other cladding materials that is not brick, timber, or fibre cement sheets. Subclassification of other materials was not provided as part of data set analysed in this research.

The roof framing often comprises roof trusses using the same materials as the wall framing with roof covering (roof cladding) being either steel sheeting or roof tiles in concrete or terracotta. Data analysis indicates that roof tiles remain the most common materials adopted for roof cladding. Roof geometry is often the first influencing factor of material choice as flat roofs (from 2 – 5 degrees) can only be clad with steel sheeting while tiled roof structure must have a minimum pitch of about 20 degrees. The use of either material can sometimes be informed by personal choice of homeowners influenced by aesthetic and desired appearance. Notwithstanding, local building guidelines, environmental factors, availability and cost of labour required to complete the roof cladding can also inform the material choice.

IOP Conf. Series: Earth and Environmental Science 1101 (2022) 042022 doi:10.1088/1755-1315/1101/4/042022

Table 1. Proportion of materials used in residential building envelopes in Victoria between 1996–2019.

Year	Total Residential Permits	Substructure (Floor Framing)			Frame			External Wall Cladding					Roof Cladding			
		Concrete/ Stone	Timber	Other	Timber	Steel	Other	Brick Veneer	Double Brick	Timber	Fibre Cement	Other	Tiles	Steel	Concrete	Other
1997	24447	50.3%	27.5%	22.2%	54.9%	4.1%	41.0%	63.2%	2.4%	8.2%	1.3%	25.0%	47.3%	24.6%	5.5%	22.6%
1998	31226	53.5%	25.8%	20.7%	49.3%	12.0%	38.7%	65.2%	3.1%	10.5%	1.0%	20.2%	49.0%	25.4%	3.5%	22.1%
1999	36171	55.2%	24.2%	20.6%	59.6%	6.6%	33.7%	51.0%	2.6%	7.0%	0.8%	38.6%	52.8%	26.1%	1.7%	19.4%
2000	31872	56.0%	20.3%	23.8%	71.4%	4.2%	24.4%	27.5%	2.4%	2.8%	0.8%	66.6%	51.0%	30.0%	1.5%	17.5%
2001	36895	54.1%	18.6%	27.2%	70.6%	4.8%	24.6%	24.8%	1.1%	2.3%	0.6%	71.3%	47.0%	31.0%	1.0%	20.9%
2002	40004	54.5%	18.4%	27.1%	72.6%	3.9%	23.4%	26.1%	1.1%	2.2%	0.4%	70.2%	47.8%	31.1%	1.0%	20.1%
2003	39246	51.5%	17.6%	30.9%	71.1%	4.5%	24.4%	24.4%	1.1%	2.1%	0.5%	71.9%	44.7%	31.9%	0.9%	22.5%
2004	37156	50.4%	17.1%	32.4%	70.8%	4.6%	24.6%	28.1%	1.2%	3.3%	0.5%	67.0%	42.4%	34.1%	0.8%	22.7%
2005	35062	56.1%	15.8%	28.1%	73.2%	5.0%	21.8%	31.2%	1.8%	4.0%	0.8%	62.1%	44.0%	34.4%	0.6%	21.0%
2006	35012	56.0%	15.7%	28.3%	73.5%	5.1%	21.4%	47.7%	0.8%	6.2%	0.8%	44.5%	44.9%	30.8%	0.7%	23.7%
2007	36528	60.8%	16.4%	22.9%	78.2%	5.9%	15.9%	63.9%	0.8%	7.7%	1.1%	26.4%	48.9%	29.5%	0.8%	20.7%
2008	37700	63.0%	16.5%	20.5%	79.8%	5.4%	14.8%	65.6%	1.0%	7.3%	1.3%	24.8%	51.7%	27.7%	1.0%	19.7%
2009	42369	67.0%	14.5%	18.5%	81.5%	4.6%	13.9%	70.4%	0.8%	6.0%	1.5%	21.3%	54.7%	26.4%	0.5%	18.3%
2010	45640	67.0%	13.9%	19.1%	81.4%	3.7%	14.9%	69.8%	0.8%	5.5%	1.5%	22.4%	53.5%	26.4%	0.5%	19.6%
2011	39554	66.9%	11.8%	21.3%	79.4%	4.1%	16.5%	67.4%	0.5%	5.4%	1.4%	25.2%	50.9%	27.7%	0.4%	20.9%
2012	36173	67.5%	11.7%	20.8%	79.0%	4.9%	16.2%	67.6%	0.5%	5.1%	1.7%	25.1%	49.4%	28.9%	0.5%	21.1%
2013	35738	61.1%	8.9%	29.9%	70.3%	4.5%	25.1%	58.3%	0.5%	4.5%	1.8%	34.9%	42.0%	27.5%	0.5%	29.9%
2014	40484	56.3%	7.7%	36.0%	64.4%	4.7%	30.9%	53.5%	0.7%	4.0%	1.6%	40.2%	37.5%	26.2%	0.6%	35.8%
2015	42577	57.8%	8.2%	34.0%	67.0%	4.4%	28.7%	53.9%	0.6%	4.7%	1.9%	38.9%	38.4%	27.0%	0.7%	33.9%
2016	45126	58.8%	8.7%	32.5%	67.8%	4.4%	27.8%	55.4%	0.7%	4.2%	2.1%	37.6%	39.3%	27.0%	1.2%	32.5%
2017	47814	61.9%	8.1%	30.1%	69.1%	5.0%	25.9%	55.6%	1.1%	4.1%	1.9%	37.3%	40.0%	28.4%	0.8%	30.8%
2018	47532	72.0%	6.8%	21.2%	76.4%	5.3%	18.4%	62.1%	0.8%	3.6%	2.3%	31.3%	44.5%	30.1%	1.2%	24.1%
2019	20936	82.7%	6.4%	10.9%	85.6%	5.2%	9.1%	69.3%	0.8%	3.4%	2.9%	23.7%	48.9%	34.5%	1.5%	15.1%

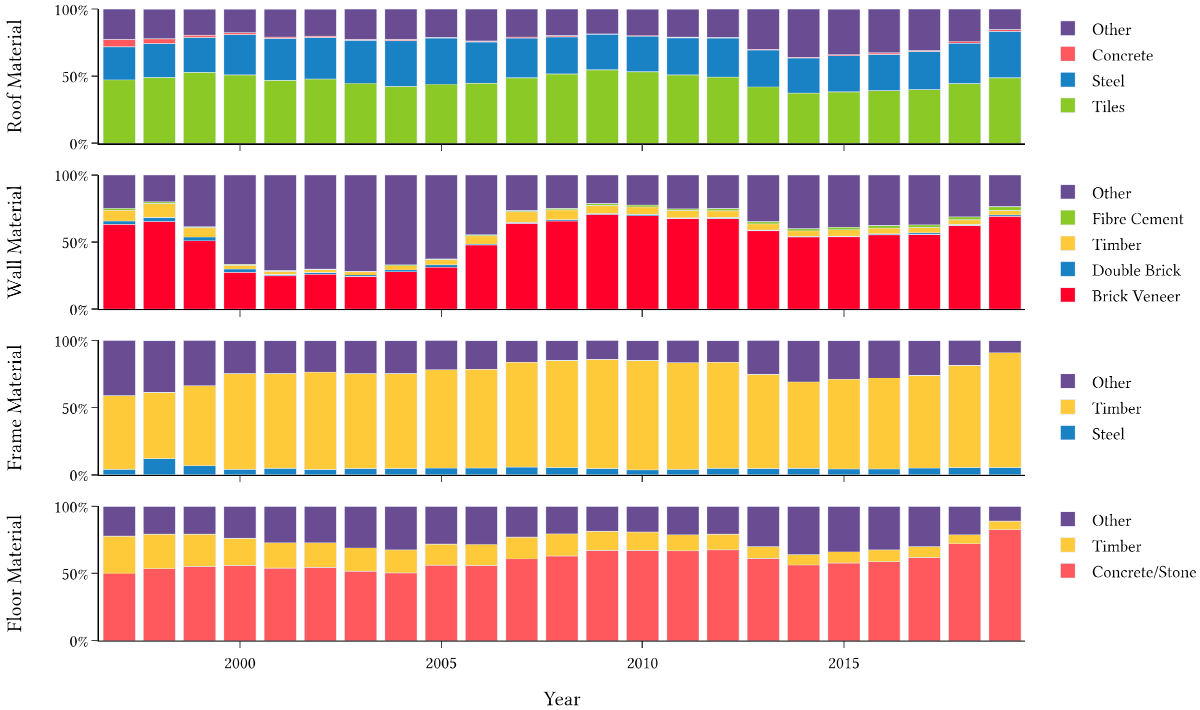

Figure 1. Adoption of building materials over time for residential buildings (1996-2019).

4.2. Geographical distribution of materials

Figure 2 depicts the geographical distribution of materials over the Local Government Areas (LGA) across the state of Victoria while presenting a contrast of materials usage between urban and regional settings. Data screening revealed that roof cladding with tiles and wall cladding with brick veneer are more prevalent in metropolitan areas. Such distribution could be influenced by urban setting requirements within the LGAs as well as applicable requirements from the residential code tailored to suit family dwellings which constitute a significant proportion of residential buildings within urban settings. Most notable is the shift in using steel frames for residential buildings constructed in regional areas. Termite infiltration is usually a problem for buildings situated in regional areas. With steel framing being impervious to termite attack, it therefore qualifies as a termite resistant material and accounts for its increased adoption beyond the metropolitan fringe. Most residential buildings in regional areas will also be located within a bushfire region. Satisfying compliant performance requirements necessitate the use of non-combustible framing materials. Steel framing is therefore highly suitable in designated fire prone regions for its ability to limit the spread of fire as such framing reduces the risk of fire spread to adjoining buildings.

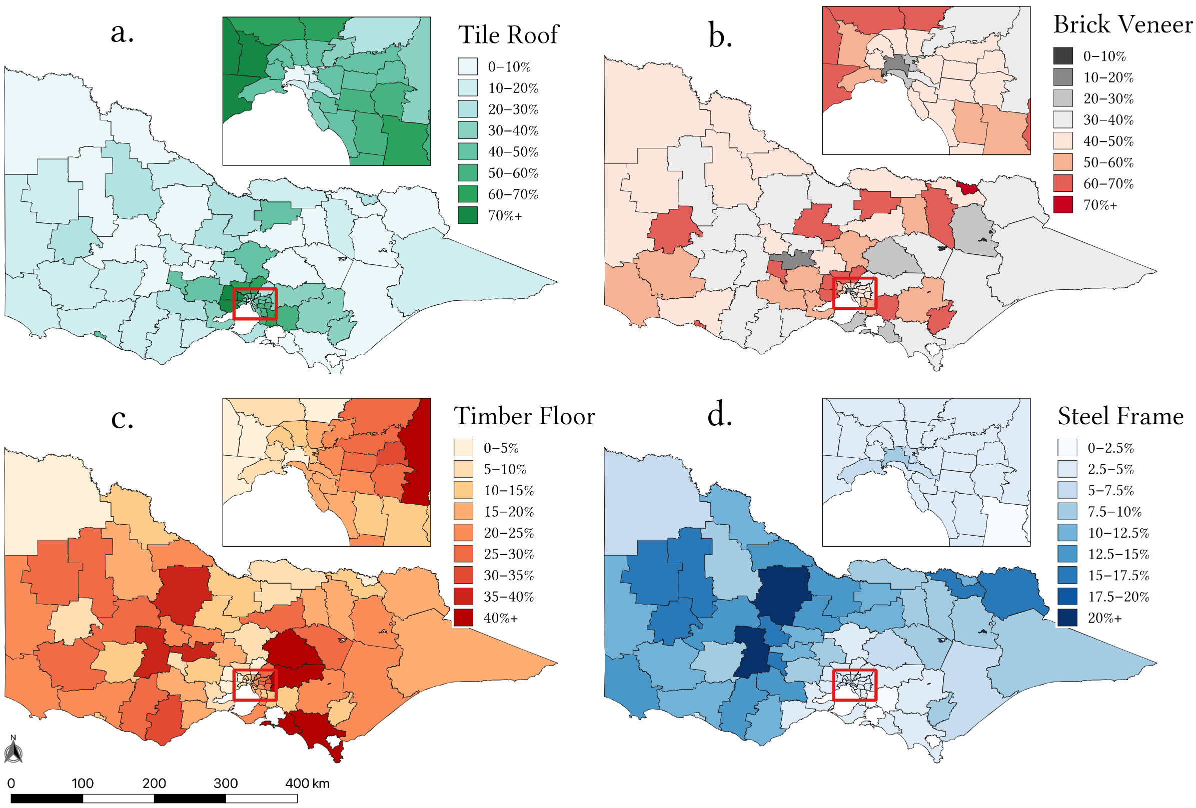

Figure 2. Maps showing permit proportion across Local Government Areas for: a. tiled roofs; b. brick veneer walls; c. timber floors; and d. steel frames.

5. Conclusions and further research

This research presents information and data around trends in materials used for constructing the building envelope of residential buildings in Victoria. Characteristeris of materials used were obtained from building permit application data provided by the Victorian Building Authority. Quantititative analysis of materials used for the building envelope revealed that over time, while the majority of residential houses are framed with timber, this material is most popular with houses built wihin the metropolitan areas in Victoria. Steel wall framing and metal roof cladding remain the most common framing and cladding materials in regional areas designated as fire prone regions requiring non-combustible framing and cladding materials. Building code requirements for houses built in regional areas further necessitate termite resistant materials, and using steel framing elliminates the danger of termite attack and also eradicates the need to install physical termite barriers. While concrete slab on ground and brick veneer construction remains the dominant system used in the building envelope across the state, there has been a decline in using veneer as wall cladding in regional areas. Analysis of the data also demonstrates minimal innovation in materials used in the construction of building envelopes, despite its critical role in the functioning of residential buildings.

Results from this research will provide insight to inform policy for various maintenance regulations deemed appropriate for metropolitan and regional areas and further provide a context around performance requirements for the materials recommended for the various geographical settings. To further contextualise materials adoption for residential buildings, further research is required to evaluate the correlation with other project parameters such as project cost, site allotment area, number of storeys and building floor area which were not included in this aspect of this study.

It should be noted that data used in this research is limited to private sector building permits issued between 1996 to 2019. The private sector building permits for residential buildings however represents the significant portion of annual building permits.

6. References

[1] ABS 2017 Building Activity, Australia, Mar 2017. Cat. No. 8752.0 Australian Bureau of Statistics Canberra, Australia [Accessed 20 September 2021]
[2] HIA 2017 Contribution of the Housing Sector to the Australian Economy Housing Industry Association Canberra, Australia [Accessed 27 September 2021]
[3] ABS 2021 Building Approvals Australia - 8731.0 Australian Bureau of Statistics Canberra, Australia [Accessed 20 September 2021]
[4] DELWP 2016 Victoria in Future 2016 – Population and household projections to 2051 VIC: Department of Environment, Land, Water and Planning, Victoria State Government
[5] ABCB 2019 National Construction Code Series 2019. Building Code of Australia, Vol.2 – Class 1 and 10 Buildings. Canberra , Australia: Australian Building Codes Board
[6] AS1684.2 2021 Residential timber-framed construction Non-cyclonic areas Australia: Standards Association of Australia
[7] AS2870 2011 Residential Slabs and Footings - Construction Australia: Standards Association of Australia
[8] AS4773.1 2015 Masonry in small buildings; Part 1: Design Australia: Standards Association of Australia
[9] AS4773.2 2015 Masonry in small buildings; Part 1: Construction Australia: Standards Association of Australia
[10] Paton-Cole V P and Aibinu A A 2021 Construction defects and disputes in low-rise residential buildings *J. Legal Affairs and Dispute Resolution in Engineering and Construction* **13** 05020016
[11] Badrock G 2016 Post incident analysis report: Lacrosse Docklands Proc. of MATEC web of conferences Malaysia: EDP Sciences Malaysia p. 06002
[12] Nunweek J and O'Hanlon B 2019 Overcrowding: regulatory problems and proposed responses *J. Parity* **32** 12-4
[13] Taskforce V C. Victorian Cladding Taskforce: report from the Co-Chairs July 2019: Department of Environment, Land, Water and Planning (Vic); 2019.
[14] Johnston N and Reid S 2019 An examination of building defects in multi-owned properties Vic, Australia: Deakin and Griffith Universities
[15] McKenna S T, Jones N, Peck G, Dickens K, Pawelec W, Oradei S, Harris S, Stec A A and Hull T R 2019 Fire behaviour of modern façade materials–Understanding the Grenfell Tower fire *J. Hazardous materials* **368** 115-23
[16] Peng L, Ni Z and Huang X 2013 Review on the fire safety of exterior wall claddings in high-rise buildings in China *J. Procedia Engineering* **62** 663-70
[17] Ye W-x 2016 Investigation and identification of fire caused by setting off fireworks *J. Procedia Engineering* **135** 427-30
[18] Badam R 2012 Life-Saving Action by Fire Heroes as Dubai Building Engulfed by Flames The National UAE.
[19] Bannister A 2015 Dubai Inferno: 5 of History's Worst Skyscraper Fires IFSEC GLOBAL South East Asia.

[20] HIA 2018 An investigation of the factors influencing framing material choice in residential building Australia: Forest Wood Products Australia
[21] Page A W 1996 Unreinforced masonry structures *J. Bulletin of the New Zealand Society for Earthquake Engineering* **29** 242-55
[22] Martins A, Vasconcelos G and Costa A C 2017 Brick masonry veneer walls: An overview *J. Building Engineering* **9** 29-41
[23] Dewsbury M, Law T, Potgieter J, Fitz-Gerald D, McComish B, Chandler T and Soudan A 2016 Scoping study of condensation in residential buildings-Final report Australia: University of Tasmania
[24] Thomas D and Ding G 2018 Comparing the performance of brick and timber in residential buildings– The case of Australia *J. Energy and buildings* **159** 136-47
[25] Gregory K, Moghtaderi B, Sugo H and Page A 2008 Effect of thermal mass on the thermal performance of various Australian residential constructions systems *J. Energy and buildings* **40** 459-65
[26] Moore T, Berry S and Ambrose M 2019 Aiming for mediocrity: The case of Australian housing thermal performance *J. Energy policy* **132** 602-10
[27] Rauf A and Crawford R H 2013 The relationship between material service life and the life cycle energy of contemporary residential buildings in Australia *J. Architectural Science Review* **56** 252-61
[28] Janjua S, Sarker P and Biswas W 2019 Sustainability assessment of a residential building using a life cycle assessment approach *J. Chemical Engineering Transactions* **72** 19-24
[29] Razzaghmanesh M, Beecham S and Salemi T 2016 The role of green roofs in mitigating Urban Heat Island effects in the metropolitan area of Adelaide, South Australia *J. Urban Forestry & Urban Greening* **15** 89-102
[30] Jamei E, Chau H W, Seyedmahmoudian M and Stojcevski A 2021 Review on the cooling potential of green roofs in different climates *J. Science of The Total Environment* 148407

Acknowledgments
The authors would like to acknowledge the Victorian Building Authority for providing access to the data used in this study. The authors also wish to acknowledge the use of the AURIN Data61-GNAF Geocoder when developing the data used in this study. The authors are also grateful for the invaluable support provided by the Melbourne Data Analytics Platform.