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IeGRESAFE 2022

# E-PROCEEDING OF

# 1st INTERNATIONAL E-CONFERENCE ON GREEN & SAFE CITIES 2022

"Sustaining the Resilient, Beautiful and Safe Cities for a Better Quality of Life"

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**ORGANISED BY**

Gresafe_Cities RIG
The University of Queensland, Australia
Kampus Hijau UiTM Perak

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# DESIGN FOR ADAPTABILITY AND DISASSEMBLY: TOWARDS ZERO CONSTRUCTION WASTE IN THE AUSTRALIAN HOUSING SECTOR

**Lisa Kuiri[1]*, Paola Leardini[2]**
***Corresponding Author**
The University of Queensland, Brisbane, Australia

*l.kuiri@uq.edu.au
p.leardini@uq.edu.au

***Abstract***

The built environment is the biggest consumer of natural resources globally, with construction and demolition materials among the biggest sources of waste in developed countries. In Australia, the housing sector continues to use construction methods based on a 'take-make-waste' linear model, which is an unsustainable practice for using materials on a planet of finite natural resources and increasing population. New design and construction practices are being developed internationally to target the most sustainable options for handling materials and components at a building's end of life. A transformational design shift is needed to transition the Australian housing construction market to a Circular Economy (CE), keeping materials in use for longer. However, while theoretically sound, the implementation of circular design in construction remains limited internationally, and the transition has not started in Australia yet. Based on a narrative and integrative review approach, this paper argues that an effective transition to a CE in construction, through adaptable housing models, has the potential to eliminate material waste while addressing demographic changes of diverse Australian stakeholders. This paper questions the paradigm of one household on one lot in sprawled suburbs dominated by detached housing, and advocates for alternative housing models, such as incremental housing, to increase suburban density. Enabled by advances in prefabricated timber technology, design for disassembly may augment this approach, enabling housing designed for adaptability, to grow and contract in size in response to changing household needs and desires.

***Keywords***: *Adaptable housing, design for adaptability, design for disassembly, incremental housing, prefabricated housing, scalable housing.*

## INTRODUCTION

The built environment is the biggest consumer of natural resources globally, with construction and demolition materials among the biggest sources of waste in developed countries (European Union, 2015). In Australia, the housing sector continues to use construction methods based on a 'take-make-waste' linear model (Ellen Macarthur Foundation, 2022), which is an unsustainable practice for using materials on a planet of finite natural resources and increasing population. National demand on materials for new house construction is exacerbated by the fact that the most dominant type of dwelling in Australia is the detached house on land, and contemporary Australian houses are the biggest in the world, with an average floor area of 229.6 sqm (James & Felsman, 2020; Power, 2022). Making way for mostly detached new houses in suburban sites, existing old houses are often demolished as they are regarded by owners as functionally obsolete, or the cost of renovation, alterations and additions to the existing house is comparable to the cost of a new house designed to the owner's current lifestyle needs and aspirations. The common practice of house demolition reduces materials to rubble, to be taken to landfill; construction and demolition material from the Australian housing industry comprises a significant 44% of waste in landfill, prompting a call for more recycling of building materials (Shooshtarian & Maqsood, 2021). However, even this is a 'downcycling' process, effective when more sustainable practices to reduce, reuse, refurbish and remanufacture, are not applicable (Cimen, 2021).

New design and construction practices are being developed internationally to target the most sustainable options for handling materials and components at a building's end of life. A transformational design shift is needed to transition the housing construction market to a Circular Economy (CE) keeping materials in use for longer. However, while theoretically sound, the implementation of circular design in construction remains limited internationally, and the transition has not started in Australia yet.

This paper will discuss constraints and opportunities for the implementation of circular design in the Australian housing market, including social and environmental impacts at the city scale, focusing on two key approaches that aim to increase the longevity of buildings and materials: Design for Adaptability (DfA) and Design for Disassembly (DfD). Unleashing the potential of these synergistic design approaches for the Australian housing sector is the underlying basis for a government funded research project being conducted at the University of Queensland (UQ). Leveraging preliminary results of this research, the paper will explain meaning and strategies of DfA and DfD in the specific Australian housing context, considering Australian construction tradition and adaptable housing precedents against key international adaptable housing exemplar projects.

## METHODOLOGY

In 2021, the Australian Research Council funded a research project aiming to address housing performance and affordability in Australia by deploying adaptable design for spatial reconfiguration and component reuse, to advance offsite timber manufacture towards energy efficient and healthy homes as mainstream practice. The project seeks to understand how new types of adaptable and scalable, prefabricated housing of low to medium density scale, can address specific functional, spatial and economic needs of diverse Australian households at changing life stages. This new design and construction approach has the potential to transform the way Australian cities grow and the population dynamics within the urban space. The first phase of the project has directly informed this paper, using the literature review as a research method (Snyder, 2019) to critically assess the international and Australian knowledge production on circular design and housing respectively; this enables an informed understanding of the opportunities offered by the transition to a CE of the specific Australian residential market.

A systematic collection and analysis of existing literature was conducted by the authors to support knowledge advancement in subsequent research phases (Webster & Watson, 2002). Given the interdisciplinary nature of the study, this approach was also found to be crucial to pooling sectorial knowledge and creating synergies. Based on a narrative and integrative review approach (Baumeister & Leary, 1997), this paper will argue that an effective transition to a CE in construction, though adaptable housing models, has the potential to eliminate material waste while addressing demographic changes of diverse Australian stakeholders.

To obtain knowledge of the diversity of Australian householders, Australian government organisations were consulted: the Australian Bureau of Statistics was referred to for its definitions of household types (ABS, 2019a, 2019b); the Australian Institute of Health and Welfare studies for the trends and requirements of housing for Australians that need

Government support (AIHW, 2019); and the Australian Institute of Family studies for family types (Australian Institute of Family Studies, 2022). To understand current issues affecting the design of Australian housing, literature was researched for the topic of "Australian Housing" (London & Anderson, 2008; London et al., 2017; Murray et al., 2008); historical accounts of "Australian house" (Archer, 1996; Harrison, 2010, 2013; O'Callaghan & Pickett, 2012; Saunders, 1985) and "Queensland house" (Fisher, 1991, 2016b; Fisher & Crozier, 1994; Watson, 1981).

Literature on adaptable housing, design for disassembly, and circular design was searched using three databases: Google Scholar, Scopus and Avery Architectural Index. As concepts about circular economy and circular design have only been in recent usage, the search using these terms returned publications from 2010 onwards. Two types of articles were searched for using Google Scholar: those linking circular design principles with flexible or adaptable housing, and literature reviews about circular design of buildings, adaptable or flexible architecture. This search was limited to articles that related to detached and semidetached housing, prevalent in Australia, and focusing on construction materials and methods similar to what is used for housing in the country. Scopus provided a similar result of authors and publications, with the advantage that links to referenced articles allowed snowballing to search through other relevant, older and seminal articles by authors in the field of flexible and adaptable housing. The Avery Architectural Index only provided few additional results but was useful for publications about changes in house design for environmental sustainability. The literature search returned 85 relevant publications, including the following key works that informed the review discussed in this paper: Munaro et.al (Munaro et al.) conducted a systematic literature review on the CE in the built environment; Geldermans et. al. (Geldermans et al.) explored the relationship between circular and flexible design; Askar et.al (Askar et al.) provided a critical literature review of adaptable buildings; Schneider and Till (Schneider & Till) analysed over 150 twentieth century housing projects in their seminal book Flexible Housing; Schmidt and Austin (Schmidt & Austin) defined six levels of adaptability in Adaptable Architecture: Theory and practice; and Avi Friedman's decades of conceptual and built adaptable housing in Grow Home (Friedman), Adaptable Home (Friedman), and Next Home (Friedman & Krawitz).

## CRITICAL ANALYSIS OF LITERATURE

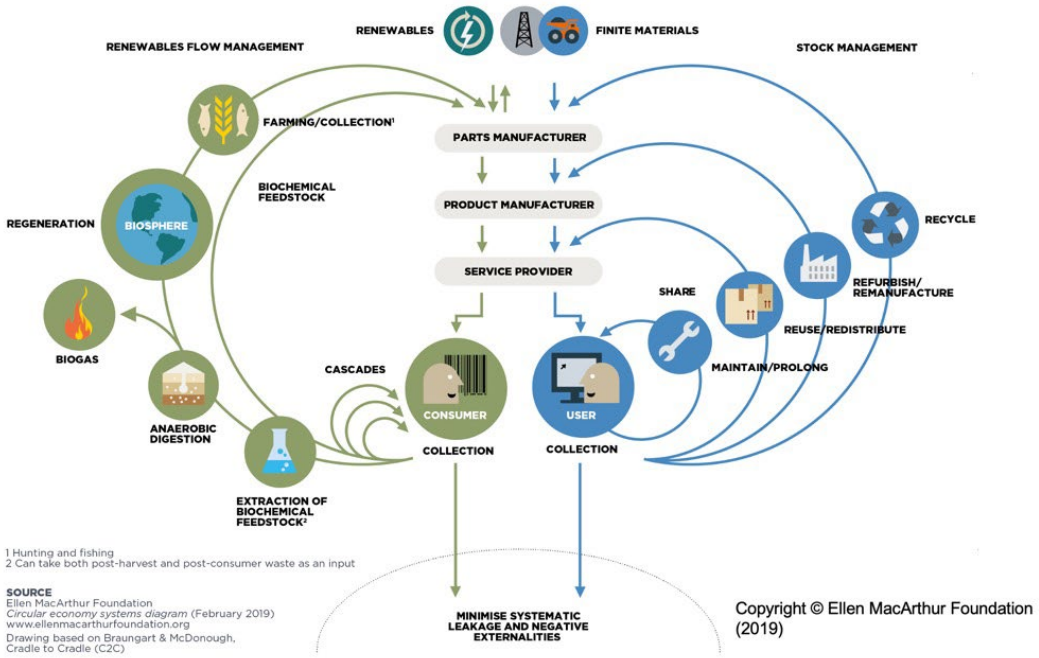
### Transformative potential of Circular Design in building construction

In most developed countries, including Australia, construction industry operates on an obsolete, 'take-make-waste' linear model (Ellen Macarthur Foundation, 2022), where natural resources are unproductively used and disposed. Growing internationally as an alternative approach to the current, unsustainable, linear system, the CE extends the life span of resources in the value chain, turning demolition costs into a positive business case: it traces feasible trajectories towards zero waste cities through "the superior design of materials, products, systems, and, within this, business models" (Ellen MacArthur Foundation, 2013, p. 7). Ultimately, half of the 17 Sustainable Development Goals requires setting circular systems in construction (Jensen & Sommer, 2018), and Australia has already committed to their implementation (United Nations, 2018).

The CE is viewed as an ecosystem where natural resources are preserved and enhance, renewable resources are optimised, waste is prevented, and negative externalities are designed out; the aim is to keep materials, products and components in repetitive loops of use, maintaining and handling them to preserve their value for longer (ARUP, 2016), as seen in Figure 1 (Ellen Macarthur Foundation, 2022).

**Figure 4**

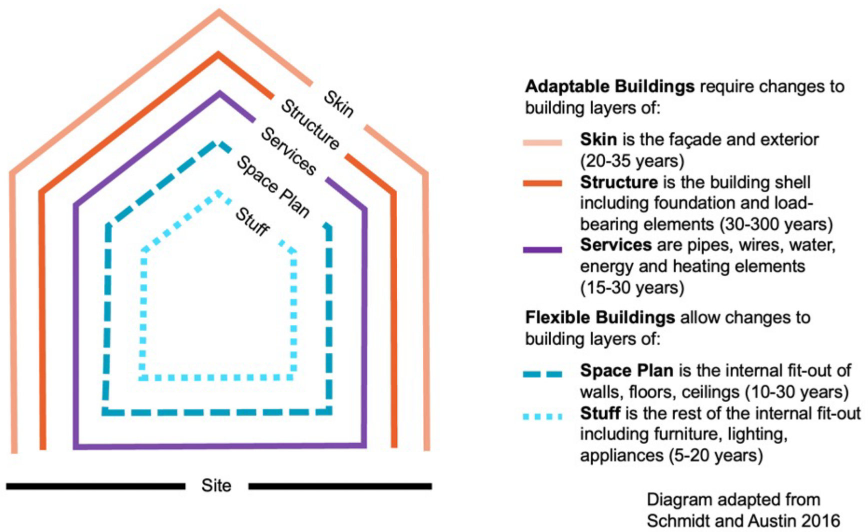
*Circular Economy Systems Diagram by Ellen MacArthur Foundation*




Literature about designing buildings towards a CE has expanded in the last few years (Munaro et al., 2020), including various guidebooks for architects on circular design in construction (Cheshire, 2016). A key circular design strategy is Brand's concept of building as 'shearing layers of change'; the inner layers is acknowledged as having shorter lifespans to enable change or replacement without affecting the integrity of the outer layers of structure, skin and site, as seen in Figure 2 (Arup and Ellen Macarthur Foundation, 2020; Brand, 1995). At a larger scale, the Ellen Macarthur Foundation has developed the ReSOLVE framework, to implement circularity to products, buildings, neighbourhoods and cities through six actions: regenerate, share, optimise, loop, virtualise and exchange (ARUP, 2016). Two of these actions, 'optimise' and 'loop', are particularly applicable to buildings and the materials they are constructed from.

**Figure 5**

*Adaptable and Flexible Building Layers, based on Brand's Shearing Layers*



**Design for Adaptability**

Optimising building materials is logically done by keeping buildings in use for longer (Minami, 2016). In the circular design literature, a key approach to increasing building longevity is to design buildings that can undergo change, and are flexible and adaptable to the changing needs of their occupants and contexts (Arup and Ellen Macarthur Foundation, 2020; Cheshire, 2016; Cimen, 2021; Manohar, 2017). DfA has become a growing area of research in the transition of the construction industry to a CE (Askar et al., 2022; Askar et al., 2021; Aziz et al., 2020; Geldermans et al., 2019; Geldermans, 2016).

Askar et al (Askar et al., 2021) (2021, p. 11-12) provide a useful definition for the concept of adaptability in buildings, aligned with the CE action of optimising buildings and their materials: "the capacity of a building to accommodate change in response to the emerging needs or varying contextual conditions, therefore prolonging the useful life while preserving the value for its users over time". In the literature, both terms 'flexible' and 'adaptable' are used and sometimes interchanged in meaning (Askar et al., 2021). In this paper though, 'flexible' buildings are understood as thoaw that allow changes of use to occur without affecting the structure, such as occupants changing the use of rooms by moving furniture or employing movable screens. However, for a building to be truly 'adaptable', more substantial changes to its physical fabric are usually required to facilitate new uses. To enable buildings to adapt without damaging the materials they are constructed from, they need to be designed for future change (Friedman, 1997; Kronenburg, 2007; Schmidt & Austin, 2016; Schneider & Till, 2007). Schmidt and Austin (Schmidt & Austin), in their comprehensive theory for adaptable architecture, analysed how buildings can be designed for adapting to change, and have defined six levels of adaptability: adjustable, versatile, refitable, convertible, scalable and movable. These categories define increasing changes to the building, from flexible buildings that can be modified by occupants themselves, with little change to the building fabric, to adaptable buildings, ranging from changing parts or changing the size of the building, to moving the building entirely to another location.

**Design for Disassembly**

Achieving the levels of adaptability defined by Schmidt and Austin (2016) as 'convertible', 'scalable', and 'movable', requires the method of construction to accommodate these anticipated changes. Physical adaptations to a building can be achieved by using modular, standardised components with reversible connections, which allow building components to be added and reconfigured (Askar et al., 2022). Prefabrication has the potential to integrate connections that are reversible during off-site manufacture, reducing the on-site time to assembly near finished components (Aitchison, 2018; Davies, 2005; Smith, 2010). Prefabrication also addresses the other key action of designing buildings for a CE, which is to keep materials in loops of use. By using prefabricated modular construction that is designed for adaptability and disassembly, building materials can be kept in loops of reuse, reducing construction waste (Dams et al., 2021); prefabricated components can be deconstructed at the end of one building's service life, to be reassembled in another location, for the same or for other projects.

These ideas of DfD at the scale of a house have been realised in the demonstration project *Cellophane House* by Kieran Timberlake (Kieran & Timberlake, 2011), built as part of an exhibition about factory-made architecture at the Museum of Modern Art in New York. The building was assembled in 'chunks' to the site, exhibited for ten months, then disassembled in pieces, stacked by like elements, catalogued and taken away for reuse. A similar project was designed and built ten years earlier with a similar intention of the metal frame to be used again: *Experimental House R128* by Werner Sobek in Germany. This steel framed house has mortice-and-tenon and bolted connections that allow it to be taken apart for the steel to be recycled

(Werner Sobek, 2000). Deciding on the materials for durability versus end-of-life reuse requires a holistic design approach and is largely project specific; however, as aluminium and steel have high embodied energy due to their manufacturing processes, the use of more renewable materials as the structural elements in housing would better fulfil circular design principles. A renewable material made from fast-growing softwood is Cross-Laminated Timber (CLT), which is composed of multiple layers, at right angles to each other and glued together, to increase its structural properties. The use of CLT in buildings construction has been increasing globally, both in commercial and residential projects, due to the main benefit of off-site fabrication, resulting in shorter construction time on site and less waste. One rare project that uses CLT and has been designed for disassembly is a commercial building in the Netherlands: *Tridos Bank Office* by RAU Architects - an exemplar sustainable building that is carbon negative (Griffiths, 2021). Other recent DfD projects are *Aeres University* in Almere by BDG Architecten, which combines a demountable steel structure and spatial planning for multifunctional use (Eromesmarko, 2022); and *The Greenhouse* in Utrecht by Cepezed, designed and built to occupy the site for fifteen years (Castro, 2018).

**Learning from International examples of adaptable housing**

After World War II, a significant architectural movement emerged in the Netherlands and Japan to address the challenge of providing adaptable buildings. The Open Building movement is based on the concept of designing the two major parts of the building for different life spans: the outer building 'support', or base building, comprising of structural walls, floors, and roof; and the non-structural 'infill', which suits the needs of the occupier, and can be removed without damaging the base building (Kendall, 2010). The concept of 'support' and 'infill' aligns with Brand's 'shearing layers of change', where each layer has a different expected lifespan: the structure layer lasts 30 to 300 years, while the space plan 3 to 30 years (Brand, 1995) - as seen earlier in Figure 2. Open Buildings were pioneered by John Habraken and others in the Stichting Architecten Research (SAR) group in the Netherlands, as an alternative approach to the homogenous and inflexible mass housing apartment buildings built after the war (Habraken, 1972; Habraken et al., 1976), and in Japan, by Utida and Tatusumi, with the design of *Kodan Experimental Housing Project* (KEP) (Ikeda & Amino, 2000) and *Century Housing Project* (Kendall & Techier, 2000; Minami, 2016). SAR group designed a system for dwelling plans in row housing and apartment buildings comprising of fixed structural walls and floors, defining the perimeter of each dwelling, and specific zones for bathrooms/kitchens and living/bedroom areas, which could vary in size according to prescribed incremental dimensions. The architects took a systematic design approach, developing rules for how the rooms could vary in size and function, and created various unit layouts to suit occupant types (Habraken et al., 1976). However, in early built projects, occupants modified the units in ways not imagined by the architects (Habraken et al., 1976); consequently, in later Open Building projects, the architects involved end-users in the design process (Kendall & Techier, 2000). The KEP housing project, which employed movable partition wall system that allowed occupants to modify the interior, was more successful, even though, in some dwellings, the partitions became stiff with age (Minami, 2016). This approach of designing and building a base building with interior fit outs added by other designers is the common approach for commercial office buildings, referred to as 'long-life, loose-fit' (Kronenburg, 2007).

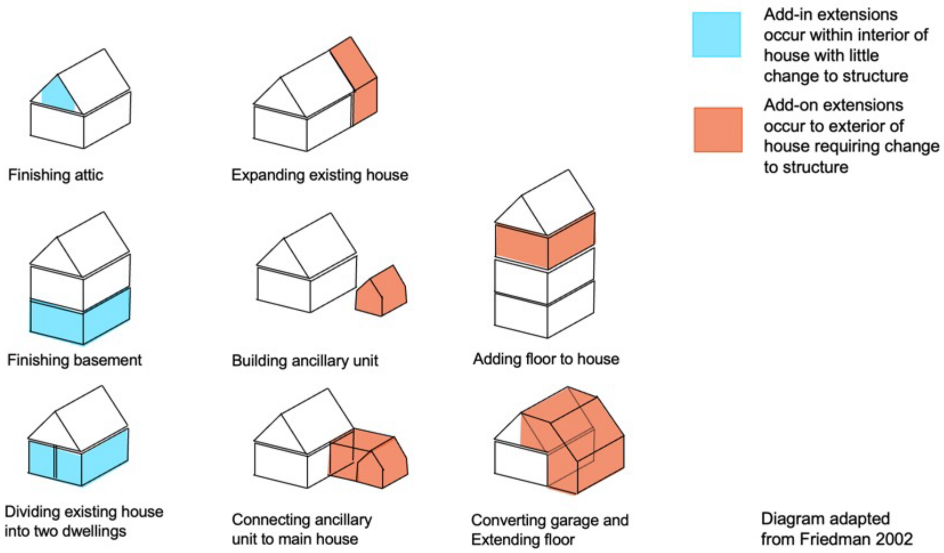
Key authors of the Open Building approach for sustainable architecture are Kendall and Teichier (Kendall, 2010; Kendall & Techier, 2000). Good examples of residential Open Buildings are *NEXT21* in Osaka, Japan (Osaka Gas Co, 2013), *Superlofts* in the Netherlands (Habraken, 2017; Koehler, 2022) and 'raw space' housing *Tila,* in Helsinki (Franke, 2014). In the *NEXT21* project there were thirteen interior architects for the eighteen infill dwellings (Kendall, 2006; Osaka Gas Co, 2013). The building façade was kept under aesthetic control by the coordinating architect stipulating rules about cladding materials and their proportions without compromising on diversity of apartment sizes and styles, and types of households in the building. Some apartments have already undergone change without any damage to the base building, demonstrating the flexibility and longevity of the design approach. In all these examples though, flexibility is implemented within fixed perimeter walls and footprint, which may imply high initial construction costs for underutilised spaces.

Incremental housing is another alternative approach in house construction, with precedents in some vernacular housing types (Rashid & Ara, 2015), that addresses affordability issue by lowering initial construction costs. The concept is to build a minimum core as a starter home, to be added on later, by the owner as self-builder, when household needs change. This progressive spatial growth is demonstrated in the plans of *Villa Verde* housing complex by Elemental, which provides a minimum habitable space for growth through an organising concept of modular masses and adjacent voids (Elemental, 2013). The building core, identical for all houses, is a single room in width, with two habitable floors, and steel floor beams spanning between cores to allow for future rooms to be built in. The owners choose the materials of built-in rooms based on availability and affordability, making each unit their 'unique' home (Figure 3).

**Figure 3**
*Villa Verde by Elemental. "Constitutión, Chile" by C-Monster CC BY-NC 4.0*

At the lower density scale of detached and semidetached houses on suburban lots, similar projects designed for growth are rare. A good example is the *Grow Home*, a terrace house designed by Avi Friedman in Canada, with unfinished space in the attic and the basement, which allows the owner to customise it according to their needs (Friedman, 2001). The *Grow Home* concept was successfully applied in Montreal, with 6000 units built from 1991-1999, and the majority of the occupants (89.4%) being first home buyers (Friedman, 2000). Later in 1996, Friedman and Kravitz designed and constructed another affordable house model at the McGill University, the *Next Home*, which allowed a prospective buyer to buy one, two or three floors (75sqm each) of a three storey terrace house (Friedman, 2002; Friedman & Krawitz, 2015). Friedman has contributed greatly to the discourse of adaptable, affordable, innovative, prefabricated, and sustainable housing since the 90s (Friedman, 1997, 2000, 2001, 2002, 2013, 2021). He has theorised that detached houses can be extended in future stages in various ways, referring to 'add-on' and 'add-in' methods (Friedman, 2002, 2013), as seen in Figure 4.

**Figure 4**
*Friedman's Add-in, Add-on Methods of Extension to a Detached Dwelling*




A house can be extended using 'add-in' methods, with unfinished spaces filled in later, such as in the *Grow Home*; while a house extended by 'add-on' methods requires space around the house, or above it, and undertaking these changes using conventional housing construction would require partial demolition to build external additions. Instead, prefabrication construction of building parts, to be assembled and disassembled, could result in reduction of demolition waste when adapting a house to changing needs, aligning Friedman's extendable houses concept with circular design principles. The emerging technology of DfD combined with DfA have the potential to disrupt future housing projects. However, there is a need for research in this still largely unexplored combined field of design, specific at the scale of low-density housing types that is significant for the Australian housing context.

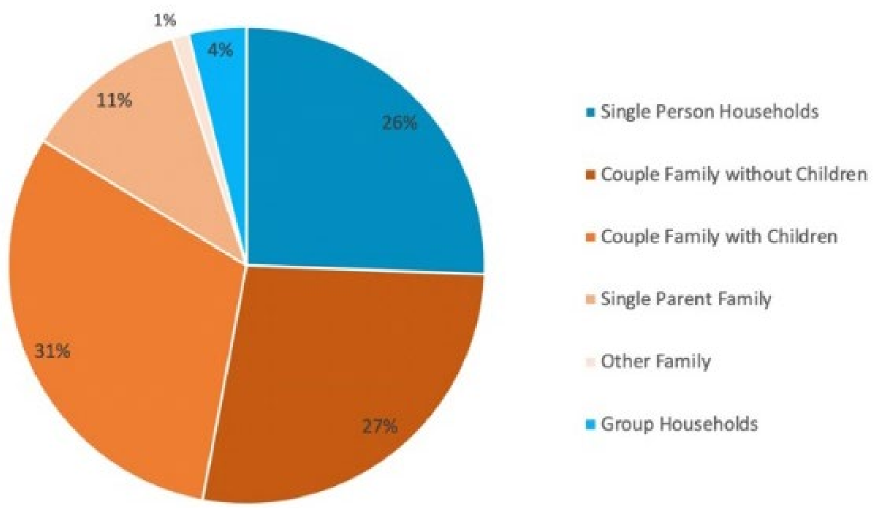
**Australian Housing Context**

A new house in Australia uses conventional construction materials usually fixed in a rigid configuration to suit the first house owners. When the living needs of the household change, the dwelling is conventionally 'adapted', if feasible, by an extension or other alterations to the building fabric, which can involve significant costs and disruption. Alternatively, having to move house in another location requires a household to establish new connections to neighbourhood and amenities, which can be particularly difficult for elderly people, who prefer to age in their own home in a familiar place (James et al., 2019). In fact, high mobility is common among Australian households: on average every 6-7 years for couples with children under 15, but more frequently for group households (5.5 years) and lone parents with children under 15 years (6.1 years) (Ramirez-Lovering, 2013). Adaptable housing, instead, could reduce the stresses and costs of undertaking expensive alterations or needing to move to another location.

Houses in Australia are also generally designed and built to fulfil requirements of the 'typical family'; the nuclear family of two parents and two children that has remained the default household model for housing since the baby boom after World War II. Back then, material shortages forced architects to design modest homes, usually climate responsive (London et al., 2017). However, after material restrictions subsided, architects became rather value enhancers and stylists of homes for individual households, and for successful project home builders such as Petitt and Sevitt (London et al., 2017). The typical Australian family home from the 50s to the 70s was built on a lot large enough to have a backyard, in new suburbs that expanded from the city, enabled by private car ownership. In the 80s though, Australian house sizes began to grow, mostly due to the aspirations of new European migrants, the 'supersized' lifestyles model imported from the United States, and gentrification of older dwellings in inner city suburbs, spurring an interest in real estate as a means to create personal wealth (ABC, 2016; O'Callaghan & Pickett, 2012). Since the early 70s, house construction has been dominated by volume builders and market driven living styles, (James & Felsman, 2020), which offer limited customisation of the plan and room configuration to the prospective house owner (Noguchi, 2016). Over time, house sizes have doubled (from 120sqm to 230sqm), lot sizes in the suburbs have become smaller (600sqm to 400sqm or less), and the average number of people in the household have almost halved (from 4.5 to 2.6) (ABS, 2019a; Ramirez-Lovering, 2013; Wheeler, 2021).

Over the last two decades Australian housing has faced three main challenges, without being able to provide effective responses: demographic changes in the population, environmental issues and the affordability crisis (Murray et al., 2008). Demographic changes have occurred in Australian households as in other countries: improved health care has led to longer lives, resulting in an increasing ageing population (Cokis, 2020; James, 2019); birth rates of women have fallen; divorce rates have increased, creating more single parent families (AIHW, 2021); more people are living alone (AIHW, 2021); and migrant groups bring other cultural expectations of housing (Furlan, 2015; Schneider & Till, 2007). According to the Australian Bureau of Statistics(ABS), in 2021, Australia had 10.8 million households that fell into three main categories: family, the most common at 70.5%, lone person at 25.6%, and group households at 3.9% (ABS, 2022). Within the family household category, couples with children were the most common type (43.7%), followed by couples without children (38.8%), single-parent families (15.9%) and other families (1.6%) - a related person living with a family or an unrelated individual living in a family household (ABS, 2022). Comparing the percentage of family household types with the total number of households, almost a third of all households are couples with children, and more than a quarter are couples without children - essentially two person households. This means that more than half of Australian households consist of one to two persons, as seen in Figure 5.

**Figure 5**
*Percentages of Australian Household Types, 10.8 million dwellings in 2021 (ABS)*



Families having been the prevailing household group for decades, most houses are tailored to family needs, regardless of the changing needs during a household's lifecycle. While the detached house on land is the most common dwelling type (70%), with 7.56 million dwellings (ABS, 2022), there continues to be a mismatch between household types and the dwellings they occupy; for example, some single and couple household would prefer to live in smaller dwellings but there is a lack of choice in the suburbs (Kelly et al., 2011).

Addressing global climate change has become the most urgent challenge in housing design internationally: first, house design can reduce the amount of harmful GHG emissions during construction and when the house is in use; and second, resilience of buildings, communities and cities can be largely increased through design, when houses adapt to and mitigate the effects of climate change. While Australia, like other developed nations, is already on a trajectory towards achieving low energy or zero energy housing targets (COAG Energy Council, 2018a, 2018b), a tangible strategy to adaptable and more climate resilient housing is still missing.

To reduce environmental impacts of urbanisation, increasing the residential density of existing suburbs is the preferred strategy over continuing urban sprawl with low-density suburban development (Newton et al., 2022). Australian cities instead, have increased population by adding new suburbs of detached housing on separate lots, causing environmental and social problems: shrinking of natural habitats surrounding cities; increasing of infrastructure to provide for expanding suburbs; more traffic on roads and longer commute times to the outer fringe suburbs – with measurable impacts on people's health and family life (Calvert, 2022). Evidence of urban sprawl is in south-east Queensland, where Sunshine Coast to the north and Gold Coast to the south of Brisbane were formerly separated by natural landscapes but have recently joined to become a "200-kilometre city" (Spearritt, 2010). More affordable housing types for a diverse population are needed within the existing suburbs of cities and could be enabled by flexible and transitional forms of infill development.

The impact of the environmental emergency is aggravated by social and economic factors driving the housing crises. Owning a home is still regarded as an important part of Australian life (Bluett, 2017) but increasing property prices is putting the dream of buying a first home out of reach for many younger Australians. In the past two decades, the percentage of Australian households that own their own home (with or without a mortgage) has decreased from 70% to 66%, while the percentage of households that rent has increased from 27% to 32% (ABS, 2019b). The main causes of the housing affordability crisis in Australia stem from the fact that, for many decades, buying and selling houses has been seen as a pathway to wealth creation rather than simply as securing a place to live (Madden & Marcuse, 2016; Rogers & Power, 2017). In 2018, one in five households (1.86 million households) owned a residential property other than their own home; of those 71% owned one other property, 5% owned four or more (ABS, 2019b). However, disadvantages of this system include larger mortgages and higher rents. When wages remain steady, an increase in mortgage payments can cause financial stress to owner occupier households, and large mortgages taking longer to pay off can cause financial stress for older people facing retirement (Day, 2019). For tenants, rent increases can make it more difficult to save a deposit to buy their own dwelling.

The concept of a house as an economic asset rather than a place to live drives the market of oversized homes. Current market trends dictate that a house requires a minimum three bedrooms, two bathrooms, two living areas, two car garage, an alfresco dining area and other specific rooms like 'mud rooms' (James & Felsman, 2020). Houses end up having a large footprint occupying most of the lot, leaving residual tiny back yards with houses very close to each other, which leads to a perverse model of 'suburban density'. In these oversized houses on lot sizes of 400sqm or less, having a house plan that has living areas facing north and windows that catch prevailing breezes are near impossible to achieve, requiring active cooling and heating with increasing running costs. Large houses are expensive to buy for many single and couple households, and not affordable at all for those on low incomes (Calvert, 2022). There is a mismatch between the housing types available and what is suitable and affordable for smaller households and people at stages of life other than the family stage. An alternative model is needed that is tailored to young or elderly household's needs and affordable. Adaptable housing that can grow and contract with a household's size and income may provide a viable path to affordable ownership in Australia.

**Adaptable housing in Australia**

Flexible or adaptable house design is generally not well addressed by volume housing designs, which are prevalent in Australia (Ramirez-Lovering, 2013). Houses with a large footprint leave little room on site for future extensions to accommodate different functions, like a home office or secondary dwellings. Garages spaces are often the largest in a house, but are not designed to be habitable. Some house plans have a 'multi-purpose room' but this is often left-over space along hallways, with no enclosing walls to provide acoustic separation or privacy.

Yet there have been attempts to introduce flexibility in contemporary housing by Australian architects. Flexible house designs for the volume housing market have been developed by Ramirez-Lovering in consultation with a volume house builder, with a demonstration home built in Melbourne (Ramirez-Lovering, 2013). The *Adaptable House* plan has various flexibility devices: two zones to allow for two separate households, with some rooms usable by either household by closing doorways with a wall; surplus space in the front room and the two-car carport allows for more than one use. Ramirez-Lovering has also designed a duplex for two households that can be varied in size according to their changing needs (Ramirez-Lovering, 2013). Another Melbourne architect, Kerstin Thompson, has designed apartments and townhouses for the *Gore St Housing* project introducing flexible rooms whose use can be decided by the occupant (Murray et al., 2008). The concept of 'indeterminate spaces' or 'functionally neutral rooms' (Schneider & Till, 2007) is not new, having been experimented in earlier twentieth century apartments, such as *Casa de las Flores* in Madrid, in 1931 (Montellano, 2015), *Hufeisensiedlung* in Germany, in 1925-31 (Schneider & Till, 2007), and in *East Fields* in Britain, in 1968 (Schneider & Till, 2007).

Even earlier, rooms of equivalent size were characteristic of certain vernacular housing types and have proven to be flexible to household's needs over time, such as in the traditional Queenslander (Watson, 1981), London cottages (Schneider & Till, 2007) and Victorian terrace houses (Brand, 1995).

In addition, Australia has long embraced the highest level of house adaptability according to Schmidt and Austin (2016): mobility. Since early settlement days, it has been common practice to relocate lightweight timber Queenslander houses, extend or reconfigure them (Fisher, 2016a; Hall, 2010). Australia has also a history of prefabricated houses dating back to the 18th century, when the European settlers used to import flat-packed timber buildings from UK and Asia due to shortage of manufacturing facilities, material and skilled labour (Archer, 1996; Fisher & Crozier, 1994; Watson, 1981; Wilson, 2018). This tradition, which is still alive, may provide the cultural foundation and social acceptance for a new generation of adaptable housing.

**Timber construction for full circle housing**

Circular design requires a holistic approach that span the whole life cycle of a building, from the choice of materials, components, and construction methods to its end of life. In this perspective, timber prefabrication has been recognised as the technological means to constructing circular and adaptable housing.

While timber construction is well established in Australia, its conservative building industry remains "overwhelmingly dominated by traditional construction methods": prefabrication represents only 3% of the $218 billion Australian construction industry (Heath & Crough, 2017) - while it is an emerging and rapidly growing technology globally (World Economic Forum, 2016). Prefabricated timber construction, which represents a fraction of this segment, is mostly neglected in the current research arena, despite its environmental and economic potential and its long tradition in Australia (Li et al., 2017). Shifting the Australian construction sector towards wood products would result in substantial reductions of Australia's carbon emissions, supporting a material that could be locally and sustainably sourced.

Even though prefabricated timber manufacturing is actually concealed within the traditional residential sector in multiple forms, from truss and wall framing, to bathroom pods (Li et al., 2017, p. 9), circularity in construction is more directly associated with Engineered Wood Products (EWPs), which represent a growing market segment in Australia, including prefabricated systems based on traditional timber construction, and composite technologies where mass-timber is combined with steel or concrete.

The growing prefabricated timber construction sector has the greatest potential for transitioning to a CE model due to the environmental benefits of timber through carbon sequestration, and the material's structural and hygrothermal performance, coupled with flexibility of modular systems (Jensen & Sommer, 2018, p. 80). Systemic changes in circular design processes (from components to the whole building) and tools remain yet unexplored, as is their potential to boost the Australian prefabricated timber construction sector, with cascading beneficial effects on building affordability, adaptability, and long-lasting performance.

## DISCUSSION

### Why should the Australian Construction Industry Transition to a CE?

While international cutting-edge research considers CE an "irreversible transition to a sustainable economic system" (European Commission, 2020), in Australia, circularity is still in its infancy; a context specific definition of CE has not been developed yet, nor an implementation path in response to local resources, market profiles and their value chains.

The 2018 report on the waste and recycling industry in Australia (Environment and Communications References Committee, 2018, p. 20) urged the Government to embrace a circular economy through "collection, recovery and re-use of products", sustained by a new regulatory framework and infrastructural investment. However, most governmental actions seem to be rather driven by the shared concern about the large amount of municipal waste produced in Australia, which ranks eighteenth of all OECD countries (OECD, 2020). Benefits of CE span far beyond the waste recycling industry; the full exploitation of circularity in construction requires re-thinking the whole building life cycle to implement the primary CE business models that rely on the expended life of products and building systems through maintenance, upgrades and retrofits, and recycled materials into as-new resources (Stahel, 2016). When coupled with energy and material efficiency, and reduced consumption patterns, circularity in construction shows the greatest potential in the reduction of global greenhouse gas emissions (GHG) (European Commission, 2020). Housing adaptability, in particular, may address not only the environmental imperative, but also the social emergency driven by a lack of affordable dwellings able to effectively accommodate needs and aspiration of diverse households.

### Pathways for DfA and DfD in Australian Housing

Combining the two approaches of DfA and DfD has not yet been attempted in the development of novel housing types for the Australian housing market and climatic context.

Much literature on CE is still at the theoretical scale and applies to buildings of any type, while there is limited application to housing types of smaller scale than apartment buildings.

In the literature on adaptable housing, Schneider and Till (2007) preferred soft strategies such as indeterminates spaces that occupiers could modify themselves, over hard strategies that were predetermined by designers; this viewpoint was informed by the fact that only few buildings they studied had components that could successfully be disassembled and reconfigured. Schmidt and Austin (2016), who developed six levels of adaptability across different building types, found that more than a third of these adaptable buildings were both versatile (adaptable space) and convertible (adaptable use); however, very few buildings were scalable (adaptable in size) and none were movable (adaptable in location), which means that the highest levels of adaptability remain largely unexplored in current practice. Despite this gap, incremental housing, which belongs to the scalable housing category, has precedents in vernacular design and has been used as a solution for starter home, as discussed earlier. Houses that can grow in stages has been theorised by Friedman for detached, row houses and low-rise apartment buildings (Friedman, 2001, 2002; Friedman & Krawitz, 2015), yet a prefabricated building system that facilitates this growth is yet to be developed. Friedman has successfully developed adaptable house models based on providing unfinished spaces within the envelope of the house. Similar models of detached and attached housing that are spatially flexible 'within' have been developed in Australia (Murray et al., 2008; Ramirez-Lovering, 2013), yet models of housing that are scalable in a systematic way are yet to be developed.

There is a gap in understanding how common and emerging housing types could provide adaptable and scalable housing configurations for the diverse cohorts of households in Australia. There has been no comprehensive survey of housing flexibility/adaptability needs of different cohorts of Australian households, except for limited work on the needs of older people to age in place, and of others with physical needs, which has resulted in mandatory standards added to the National Construction Code 2022 (Brenni, 2021; Livable Housing Australia, 2017). Understanding the needs of a changing demographic though, is key to inform alternative and innovative housing models based on adaptability and disassembly (Geldermans et al., 2019; Pomponi & Moncaster, 2016).

Finally, there is also a gap in knowledge of a prefabrication construction systems designed for assembly, disassembly and reuse that keeps materials in use beyond one building life cycle. These systems have been demonstrated in some projects internationally. Theoretically, prefabricated houses can be built in stages, as they are often planned via a modular approach; however, their buildability, in terms of systemic changes to allow building growth to occur, has rarely been addressed. Reversing the process of expansion, to contract a building to its original smaller base or core starter form through disassembly, is currently unknown in Australia and will be attempted in the research project undertaken by the UQ team, critically informed by the literature review presented in this paper.

## CONCLUSION

The construction industry, both internationally and in Australia, needs to transition to a CE to achieve international carbon emission reduction targets. This transition requires transformational changes in both building technology and housing culture.

In Australia the uptake of circular models by the construction industry is slowed down by the prevalent view of houses as an asset rather than a place to live; this has also profoundly affected housing affordability and cannot continue to be the dominant narrative for owning a home. Focussing on the dwelling as a place to live and creating a framework for adaptable, scalable housing that suits diverse households and different stages of life is a view that needs to be brought to the foreground of discussion about housing design.

The adaptable and scalable housing models for Australia explored in this paper could lead to viable solutions to pressing issues in housing related to changing demographics, the need for climate and social resilient housing, and the lack of affordable solutions, which mostly affect low income and vulnerable households. Spatial and functional models of housing that can grow and contract, to suit specific stages of household life, represent an alternative viewpoint to the current view of houses as static objects that exist on a site for decades, until regarded as obsolete. This paper questions the paradigm of one household on one lot in sprawled suburbs dominated by detached housing and advocates for alternative housing models to increase the suburban density. Building only what is needed for each stage of a household life has precedents in vernacular architecture and has been explored in recent years in international setting, through the long-term construction process known as incremental housing. Driven by advances in prefabricated timber technology, DfD may augment this approach, enabling housing to grow and contract in size to achieve the adaptability level of scalable housing. A starter home for one or two people can be small, using less materials and costing less to build than a large, family sized home at the outset. Scalable housing could be an affordable pathway to home ownership; when combined with off-site timber manufacturing, this model provides a tangible and effective way to implement circular principles in construction, paving the way towards zero material waste, and to transition cities to a CE.

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Sekian, terima kasih.

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