Adaptable and scalable housing for Australian households and stages of life

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Abstract: The housing sector in Australia continues to be dominated by construction methods based on a linear take-make-waste model: an unsustainable approach for using materials on a planet of finite natural resources and increasing population. Demand on materials for new house construction is exacerbated by the fact that contemporary Australian houses are the biggest in the world; making way for these new larger houses in suburbs, old houses are often demolished, reducing materials to rubble in landfill, as they are generally regarded by owners as functionally obsolete and are not easily adaptable to accommodate their lifestyle needs and aspirations. A transition to a Circular Economy is needed in the design and construction of Australian housing, to keep materials in use for longer by increasing the longevity of a building lifecycle or allowing materials to be used again at the building's end-of-life. Prefabrication represents an effective pathway to implement circularity in construction allowing adaptable buildings to be designed for assembly of components with reversible connections that could be easily disassembled for spatial reconfiguration on site or reuse in other buildings. This paper discusses the benefits of combining the two key circular design principles of adaptability and disassembly for developing housing types that suit spatial needs of typical Australian households at different stages of their life by the construction process of incremental growth. The study employs qualitative methods including case study analysis of contemporary adaptable, incremental housing projects and traditional vernacular housing built for growth, through the lens of circular design.

Keywords: adaptable housing; scalable housing; Design for Adaptability; incremental housing.

1. Introduction

The housing sector in Australia continues to use construction methods based on a linear 'take-make-waste' model (Ellen Macarthur Foundation, 2015), an unsustainable approach for using materials on a planet of finite natural resources and increasing population. Detached houses on land still represent the dominant type in Australia: 70% of 10.8 million dwellings in 2021 (ABS, 2022b). Demand on materials for new house construction is exacerbated by the fact that contemporary Australian houses are the biggest in the world, with an average floor area of 229.6 sqm (James and Felsman, 2020). New houses built in

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established suburbs are replacing existing, older houses which are regarded by owners as functionally obsolete; this process is driven by costs of renovation, alterations and additions to the existing house being comparable to those of a new house designed to the owner's current lifestyle needs and aspirations (Williams, 2022). The common practice of house demolition, otherwise known as knock-down-rebuild (KDR), reduces building materials to rubble in landfill - even if parts of the house still have years of service life in them. Construction and demolition (C&D) material from the Australian housing industry comprises a significant 44% of waste in landfill, which has prompted a call for more recycling of building materials (Shooshtarian and Maqsood, 2021). However, recycling is a downcycling process and at the lowest end of the hierarchy of processes for sustainable handling of materials. For example, recycling concrete involves breaking it into smaller pieces for use as road base or aggregate and no longer possessing structural strength inherent in its original form. Instead, other sustainable processes aim to retain the quality of an original product or keep the material in use longer, through multiple life cycles. Known as the "10 R's", these strategies are ranked, from higher to lower effectiveness as follows: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover (Cramer, 2017). The Australian housing construction industry needs to rethink how to keep materials in use for longer; this is a key principle in designing buildings for a Circular Economy.

This paper discusses the need for transitioning the Australian construction industry to a Circular Economy and presents two key implementation strategies for circular buildings: design for adaptability and design for disassembly. The paper also discusses the importance of linking these design strategies to the users of the buildings and identifies the prevalent types of Australian households - with specific spatial needs. In the last section, precedents of housing projects designed for growth are then analysed, including post war Australian housing, vernacular housing, and international projects of adaptable and incremental housing. The concluding premise of this paper is that novel housing models designed for adaptability and incremental growth could lead to more sustainable handling of materials and potentially better suit (spatially and financially) the range of Australian households at various stages of life.

2. Transition to a Circular Economy in housing construction

2.1. The Circular Economy

The circular economy (CE) has grown internationally as an alternative approach to the current unsustainable linear economy. The CE is viewed as an ecosystem where natural resources are preserved and enhanced, 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 (Figure 1) (ARUP, 2016). Much of the CE literature refers to the design and manufacture of products in modern society; from this viewpoint, buildings can be regarded as large products, or compilation of products assembled together. The linear economy approach sees buildings at the end of their service life demolished and materials sent to landfill, described as a "cradle to grave" approach in the pivotal book *Cradle to Cradle* by McDonough & Braungart (2002). In a CE instead, a "cradle-to-cradle" approach keeps buildings and materials in loops of use (McDonough and Braungart, 2002). Literature about designing buildings for a CE, termed 'circular design' (CD) (Cheshire, 2016; Baker-Brown, 2017), has expanded in the last few years (Munaro et al., 2020). A key concept underpinning the reuse of materials and component in construction is Brand's "shearing layers of change" (Brand, 1995); it acknowledges in the design of buildings that the outer layers of 'site', 'skin' and 'structure' have longer life spans than the inner layers of 'space' and 'stuff', thus change or

replacement of the inner layers can be enabled without affecting the integrity of the outer layers (Brand, 1995; ARUP and Ellen Macarthur Foundation, 2020). At a larger scale, the Ellen Macarthur Foundation, advocacy and research organisation for the transition to a CE, has developed, in collaboration with ARUP, the conceptual ReSOLVE framework, which is applicable to products, buildings, neighbourhoods and cities, implementing circularity through six 'actions': regenerate, share, optimise, loop, virtualise and exchange (ARUP, 2016). Of these actions, 'optimise' and 'loop' are particularly applicable to the reuse of buildings and the materials they are constructed from.

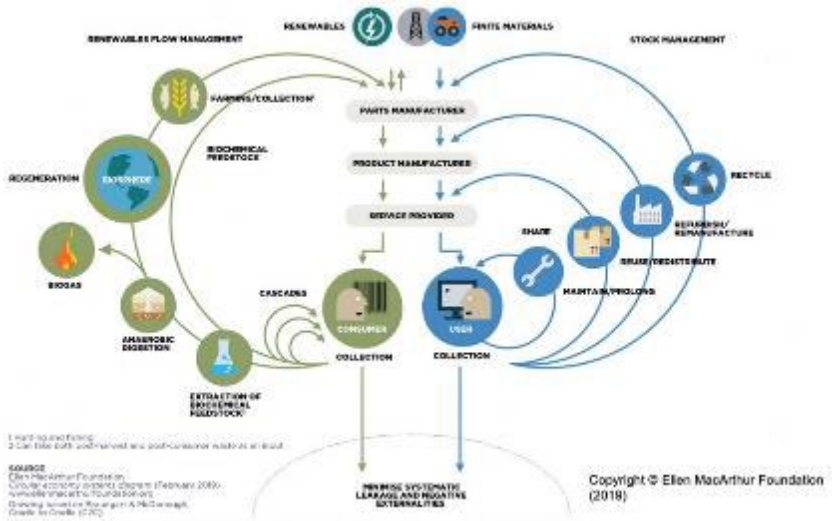

Figure 24 Biological and technical cycles of a Circular Economy (Source: EMF 2022)

2.2. Design for Adaptability

A logical way to keep construction materials in use for longer is to extend the service life of buildings. In the CD literature, a key approach to increasing building longevity is to design buildings that are flexible and adaptable to the changing needs of their occupants and contexts (Cheshire, 2016; Manohar, 2017; ARUP and Ellen Macarthur Foundation, 2020; Cimen, 2021). Hence a growing area of research in the transition of the construction industry to a CE is Design for Adaptability (DfA) (Geldermans, 2016; Geldermans *et al.*, 2019; Aziz *et al.*, 2020; Askar *et al.*, 2021; Askar *et al.*, 2022). In the DfA literature, the two terms 'flexible' and 'adaptable' are both used and sometimes interchanged in meaning (Askar *et al.*, 2022). In this paper, the definitions for flexible and adaptable buildings are based on the work of Schmidt & Austin (2016); through case study analysis of over 300 adaptable buildings, they developed a comprehensive theory for adaptable architecture that defines six levels of adaptability: adjustable (change in furniture), versatile (change in space), refitable (services), convertible (use), scalable (size) and movable (location). These levels are in order of increasing change to the building: from 'flexible' buildings, that can be modified by the occupants themselves with little change to the building, to 'adaptable' buildings, which range from changing building parts, to changing the size of the building, to moving it entirely to another location. Schmidt and Austin's case study analysis found that more than a third of buildings were both versatile and convertible; however, very few were scalable, and none were movable.

To enable buildings to change without damaging the materials they are constructed from, they need to be designed for future change (Friedman, 1997; Kronenburg, 2007; Schneider and Till, 2007; Schmidt and Austin, 2016).

2.2. Design for Disassembly

Achieving the adaptability levels defined by Schmidt and Austin (2016) as convertible, scalable, and movable, requires the method of construction to accommodate anticipated changes. Prefabrication, through off-site construction of building parts to reduce on-site assembly of near finished components (Davies, 2005; Smith, 2010; Aitchison, 2018), has the potential to allow for changes in building configuration. By using modular, standardised components with reversible connections, buildings could be adapted and reconfigured (Askar et al., 2022). Prefabricated modular construction that is designed for adaptability and disassembly could keep building materials in loops of reuse, reducing construction waste (Dams *et al.*, 2021). Design for Disassembly (DfD) is an emerging branch of prefabrication that enables components to be disassembled at the end of one building's service life, to be reassembled in another location, for the same or for other projects. Few recent examples exist to demonstrate these concepts in reality (Kuiri and Leardini, 2022); for example, the *Cellophane House* by Kieran Timberlake is a seminal project built from aluminium off-the-shelf components (Kieran and Timberlake, 2011). In this demonstration project, disassembly was made possible using bolt and plate connectors between the aluminium post and beams, visible through glass wall cladding and flooring. The four-storey building was constructed off-site in completed parts called 'chunks', delivered to site in front of MOMA in New York and assembled in a specific order, on display for ten months, then disassembled completely with like materials collected into piles for storage and future use (Kieran and Timberlake, 2011).

2.3. Links between construction waste, housing design and householders

The links between construction waste piling up in landfill, the need to design housing for the CE and the potential impact on householders, are not yet apparent. Pomponi and Moncaster (2016) provided a conceptual research framework for CD and argued that, while the macro-level of urban context and the micro-level of building components have been largely investigated, there is a lack of interdisciplinary research which is critical for understanding and applying the CE to the meso-level of buildings. They suggested research should explore links between technological and societal challenges to develop solutions to be well received by intended users (Pomponi and Moncaster, 2016).

One such study was conducted by Geldermans et al. (2019) to investigate adaptable housing design in a CE for an increasing cohort of users: the multi-family household. The authors analysed adaptable housing projects built in the Netherlands, Japan and Sweden with flexible interior partitioning systems, and developed eleven *Circ-flex* criteria for housing, which were grouped into three categories of 'flexibility capacity', 'circularity capacity' and 'user capacity' - extending the circular building discourse to the user domain (Geldermans *et al.*, 2019). Their hypothesis was that "without tapping into the user domain, circular building cannot reach economies of scale in a sustainable way" (Geldermans et al., 2019, p.16). Although combining the two approaches of DfA and DfD facilitates the implementation of CD principles through prefabrication, to have greater impact, new models of housing need to be developed with an understanding of the end user perspective. Hence it is important to understanding householder types and the spatial needs of their housing in the current Australian context for designing adaptable housing in a future CE.

3. Australian households

3.1 Demographic changes in Australian households

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 (James *et al.*, 2019b; Cokis and McLoughlin, 2020); 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 (Schneider and Till, 2007; Furlan, 2015; Levin, 2016; Lozanovska, 2019). According to the Australian Bureau of Statistics, in 2021, Australia had 10.8 million households that fell into three main categories: family, the most common at 70.5%, single person (25.6%) and group households (3.9%) (ABS, 2022b).The family category is further divided into four household types: couples with children, couples without children, single parent families and other families. Comparing the percentages of family household types with the other household types, shows that almost a third of all households are couple families with children (31%), yet more than half (53%) of Australian households consist of one to two persons (Figure 2).

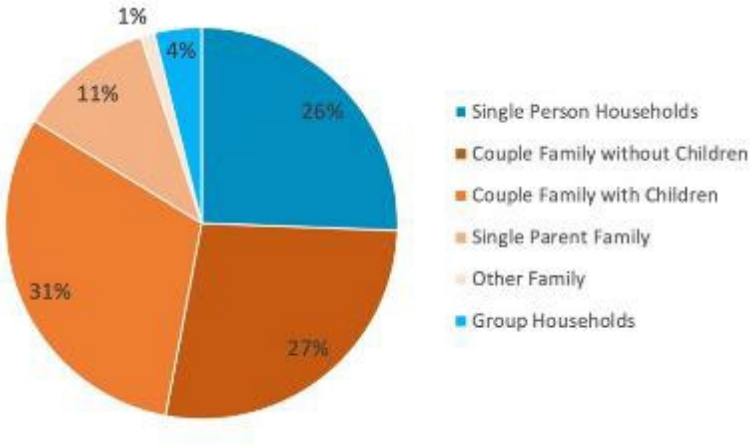

Figure 25 Percentages of Australian Households in 2021 (Figure elaborated from ABS data 2022)

Couples with children have been the perceived prevailing household type for decades and houses have been built to the needs of this family type, regardless of changes in household's lifecycle. In 2021, the detached house on land was the most common dwelling type in Australia at 70%, with 7.56 million dwellings (ABS, 2022b). However there is a mismatch between household types and the dwellings they occupy; for example, some single and couple households would prefer to live in smaller dwellings but there is a lack of choice in the suburbs (Kelly *et al.*, 2011).

3.2 Understanding different households' needs at various stages of life

Changing demographics is one of the three main issues that have affected housing design over the last two decades, together with environmental concerns and the affordability crisis (Murray *et al.*, 2008). Housing affordability continues to drive research into the state of housing, with outputs including reports

by the Australian Housing and Urban Research Institute (AHURI) (Stone *et al.*, 2020); a housing conditions data set by Baker *et al.* (2019) and reports by the Australian Government into the welfare of Australians (AIHW, 2019; 2021). AHURI has extensively researched housing aspirations of three generation cohorts of Australians: young (18-34 years), mid-life (35-54 years) and later life adults (55 years and older), with over 4000 participants surveyed across three states - NSW, Vic, SA (Stone *et al.*, 2020). Their research found a large majority of Australians across the age cohorts, income groups and housing tenures are currently housed well; however, while the house (separate or attached) meets 85% of aspirations for mid-life and older cohorts, it falls to two-thirds of young adults (Stone, Rowley, et al., 2020). Almost a fifth of young adults would like to move from a house to an apartment in areas with higher level of amenity; on the other hand, half of those young people living in an apartment stated that living in one would not meet their longer-term aspirations, suggesting that living in an apartment with high level of local amenity only suits the stage of a young person's life. Although the AHURI research provides substantial social context to understanding housing aspirations of age cohorts, household types (single person, couple family, etc.) are not specified, nor are alternative house types discussed to address their diverse spatial needs. Addressing this gap, this paper presents preliminary results of research currently undertaken at the University of Queensland, which aims to understand housing needs for diverse Australian household types at various stages of life to inform a novel adaptable housing models for a future Circular Economy.

3.3 Housing models for diverse household types

Currently building a new house in Australia follows a linear construction process, where materials are fixed in a rigid configuration to suit the living needs of the first house owners – either actual or projected. When the living needs of the household change, the dwelling is 'adapted', when feasible, by an extension or other alterations to the building fabric, which can involve significant costs and disruption to the household. Alternatively, the household have to move to another building and location, which requires establishing new connections to the neighbourhood and amenities and can be particularly difficult for elderly people, who prefer to age in their own home (James *et al.*, 2019a).

Analysis from the Australian Bureau of Statistics has found that housing mobility is strongly related to the age of persons in a household. Households with a reference person over 65 years moved less frequently than other age groups; 82% had lived in their home for more than five years, whereas 46% of households with a reference person in the 15-24 age group had moved three or four times in the last five years (ABS, 2022a). The main reasons for moving also relates to age: households with a person aged 65 years or over mostly want to downsize (22%) or be close to family and friends (13%); households in the age bracket 35-64 move into a purchased home (22%), or for family reasons such as to form a family or change in family size (15.4%), or because want a bigger or better home (17%); these three reasons were similar for households aged 25-34; households aged 15-24 move to be independent (14%) or close to education (13%). These life stages of households could be more effectively be met by adaptable housing, reducing stresses involved in moving elsewhere or costs of undertaking expensive alterations.

Yet houses in Australia are generally designed and built to fulfill requirements for when they have the most occupants: for a family. The nuclear family model of two parents and two children has remained the default household model for housing since the baby boom but is now outdated; more variety in housing models is needed to address functional and spatial needs of smaller households of one to two people, with solutions that can adapt to changing household needs through stages of life.

4. Adaptable and scalable housing

4.1 Scalable housing in Australia's past

Australia has experienced a time when housing designed for growth was considered commonplace. Immediately after World War II, immense demand for new housing combined with material shortages forced architects to design modest homes, usually climate responsive (London *et al.*, 2017). House plans were available from the architect-initiated Small Homes Service which gave low-income families access to quality, affordable home design (Maher, 2018; Monash University, 2018); some plans were designed for future room extensions when the family size and income grew (Monash University, 2018). Plans featured in newspapers and magazines, with the cost of full construction documents equivalent to several hundred dollars in today's currency (Boyd, 2015; Maher, 2018). The Service began in Victoria in 1947, expanded to New South Wales and South Australia in 1953, then Canberra in 1958 (Boyd, 2015). The typical Australian home from the 50s to the 70s was built on a lot big enough for tree in the backyard, in new suburbs away from the city, enabled by private car ownership (O'Callaghan and Pickett, 2012).

In the 80s though, Australian house sizes began to grow, due to the 'supersized' lifestyles model imported from the United States, aspirations of new European migrants, and gentrification of older dwellings in inner city suburbs, spurring an interest in real estate to create personal wealth (O'Callaghan and Pickett, 2012; ABC, 2016). Australians could afford to build large homes to accommodate their aspirations - and builders readily built them. Since the early 70s, house construction has been dominated by volume builders and market driven living styles, accommodated in extra rooms designed to suit specific functions. Current market styles include two or more bathrooms, two living areas, media and mud rooms (James and Felsman, 2020). Although volume builders offer large number of rooms in house plans, little or no customisation of the configuration is available to prospective house owners (Noguchi, 2016). From 1920 to 2020, house sizes have doubled (from 125sqm to 230sqm), lot sizes in the suburbs have decreased (600sqm to 400sqm or less) and the average number of people in a household has almost halved (from 4.5 to 2.4) (Ramirez-Lovering, 2013; ABS, 2022b; Wheeler, 2022).

4.2 Vernacular housing for adaptability and growth

Certain vernacular housing has proven to be flexible to households' needs over time. Houses with rooms of equivalent size have inherent flexibility as they can be used for different functions, such as London cottages (Schneider and Till, 2007), Victorian terrace houses (Brand, 1995) and timber Queenslander houses (Watson, 1981). In addition, Australia has a history of prefabricated houses constructed in Great Britain, shipped and assembled in the new settlement (Archer, 1996). Since early days, lightweight timber Queenslanders were relocated, extended or reconfigured (Fisher, 2016). This history of movable houses could provide the basis for cultural acceptance of novel scalable housing types in Australia.

Adaptable and scalable features are evident in some Asian vernacular housing. Traditional Japanese houses allow daily changes of occupant use in standardized room sizes based on the *tatami* mat and sliding screens (*fusuma* and *shōji*) divide rooms when needed (Schneider & Till, 2007a, p. 55). The traditional Malay *kampong* house can grow incrementally over time to suit a family's changing needs and has terminology to describe ways a house can be extended (Brand, 1995; Knapp, 2003; Rashid and Ara, 2015). Other traditional Asian houses comprise of a core house that can be extended: the Japanese house by lean-to roofs (*hisashi*); the Beijing courtyard house *(siheyuan)* within a walled enclosure has extra rooms around the courtyard; in Bangladesh, the core house (*kimma*) expands with modules (*kim-tom)* parallel to it, or rooms in the verandah *(machan)* (Rashid and Ara, 2015).

Traditional building types of warehouses, barns and factory buildings are regarded as the most adaptable types, due to their double height space and wide roof structure spans allowing an infill structure of mezzanine floor and walls for conversion into residential or other uses (Schmidt & Austin, 2016). A modern building approach for flexible buildings, conceptually similar to the convertible barn, is the Open Building movement. An Open Building is in two parts: a building shell or 'skeleton' with a longer life span and a shorter life span 'infill' organised by the occupants (Kendall, 2022). Dutch pioneers of Open Building, Habraken and the Stichting Architecten Research group, developed concepts of building 'supports' and 'infills' in the 60s and 70s for new housing projects, responding to the repetitive, inflexible mass housing built post World War II (Habraken *et al.*, 1976). At the same time in Japan, 'skeleton and infill' housing was designed by Utida and Tatusmi in the Kodan Experimental Housing Project (Ikeda and Amino, 2000; Minami *et al.*, 2022). Open Building is similar to "loose-fit" office design, where the shell is provided by the building owner and the tenant fits out the interior according to their spatial needs (Lifschutz, 2017).

4.3 Incremental housing

Incremental housing is a staged approach in house construction, with precedents in some vernacular housing types (Rashid and Ara, 2015), that addresses the issue of affordability by lowering initial construction costs. The concept is to build a minimum core as a starter home, which is then added on later by the owner as self-builder, when needs change and the household can afford the building work. This progressive spatial growth is demonstrated in *Quinta Monroy* by Elemental (Aravena and Iacobelli, 2020); the housing project provides a minimum core and space for growth through an organising concept of modular masses and adjacent voids. Each building core is a single room in width, with two habitable floors, and there are timber floor beams that span between cores to allow for future rooms to be built in. As each owner chooses the materials of built-in rooms based on availability and affordability, each dwelling attains an individual appearance that provides identity and difference - although the lack of consistency may result in a haphazard aesthetic which may not transfer well to all contexts.

4.4 Housing for growth

While similar adaptable and scalable projects at the lower density scale of detached and semidetached houses are rare, a good precedent is the *Grow Home*, a terrace house designed by Avi Friedman with unfinished space in the attic and the basement, which allows the owner to finish it according to their needs (Friedman, 2001). This concept was successfully implemented in Montreal, Canada, with 6000 units built from 1991-1999; most of the occupants (89.4%) were first home buyers (Friedman, 2000). Friedman theorised that detached houses and row houses can be extended in future stages in various ways, which he described as 'add-on' and 'add-in' methods (Friedman, 2002). The *Grow Home* was an example of 'add-in' methods, where additional rooms can be created within the building envelope. A house extended by 'add-on' methods, instead, requires space around or above it to accommodate additional volumes, and undertaking these extensions using conventional construction requires partial demolition of the house. In this scenario, prefabrication of building parts, designed for easy assembly and disassembly, could result in reduction of demolition waste when adapting a house to changing needs: an alignment of Friedman's extendable house concept with CD principles. The emerging technology of DfD combined with DfA has the potential to provide future housing models for changing households and contexts; however, there is need for cutting-edge research in this still largely unexplored combined field of design.

5. Conclusion

Much of the CD literature provides theoretical concepts that apply to buildings of any type, with limited application to housing of smaller scale than apartment buildings, which are more prevalent in Australia. To move from theory to practice, two key emerging approaches in CD are DfA and DfD, when combined, they could inform novel adaptable and scalable housing models that are implementable in low-density development for the Australian housing context.

Building only what is needed (functionally and spatially) for each life stage of a household has the potential to reduce construction waste by looping components in use. This approach has precedents in vernacular architecture and is known as incremental housing; in modern times, architects have theorised and built houses that can grow in stages. DfD may augment this building approach, enabling housing to grow and contract in size to achieve the adaptability level of scalable housing. In Australia, a starter home for one or two persons could be small, using less materials and costing less to build than a large, family-sized home at the outset; scalable housing could offer an affordable pathway to home ownership. Focussing on the home as a place to live, rather than an economic asset, and creating a framework for adaptable, scalable housing that suits diverse households at different stages of their life, could unleash a new system of handling building components for reuse on a planet with limited natural resources.

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