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Innovation for a Sustainable Low Carbon Built Environment

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Abstract

The need to rapidly transition to more sustainable low carbon built environments in Australia and internationally provides the basis for a maturation of the green economy. Its principal client will increasingly be cities, their industries and resident populations. Decarbonisation, dematerialisation and zero waste are core objectives. Regenerative retrofitting and re-shaping of cities is an associated planning challenge. This presentation will focus on innovation pathways associated with new technology, urban design, urban governance and household behaviours that are central to this transition.

Peer-review under responsibility of the organizing committee iHBE 2016.

Keywords: decarbonisation; regeneration; urban transition; sustainable built environment; mitigation; adaptation

1. Introduction

There is a growing focus on urban transitions research in planning studies [1,2,3,4,5] that reflects the magnitude of challenges now facing cities internationally. At a global level the principal challenges are associated with:

- A rapidly growing and urbanising population, estimated to reach 9 billion by 2050, two thirds urban [6].
- Exponential growth in multiple arenas of consumption over the past century ('the great acceleration') [7] that are being reflected in equivalent rates of degradation to the earth's biosphere. Such is the impact of this human activity that it is seen to be threatening the earth's 'planetary boundaries' that have delivered relatively stable conditions for the evolution of modern human settlements up until the present.

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- Increasing concentrations of human-induced CO2 in the atmosphere leading to global warming and climate change, reflected in projected increase in sea levels, storm surges, flooding and episodes of extreme heat [8].
- A growing ecological footprint (EF) that indicates population demands on the planet (in providing natural resources and absorbing wastes to land, air and water) are currently more than 50% larger than what nature can renew. The Global Footprint Network [9] reveals that ‘Carbon from burning fossil fuels has been the dominant component of humanity’s Ecological Footprint for more than half a century, and remains on an upward trend. In 1961, carbon was 36 per cent of our total Footprint; by 2010, it comprised 53 per cent’ (p.10).

Nested within this global prism are sets of national, city and local challenges that have also been clearly articulated elsewhere [1,10,11,12] and in combination with global exogenous pressures and the reality of a finite planet [13,14,15] are what establish the logic of and drivers for urban transition.

A mapping of global cities according to their estimated ecological footprints reveals a distribution that extends from low EF cities in developing and under-developed countries (with EFs below global average of 2.6gha/person) to those in high income countries, whose EFs are multiples of the world average (Figure 1). The resources that are flowing into the built environments of developed and developing countries as well as the consumption directly from the residents of these cities indicates that a significant environmental price is currently being paid to deliver high levels of urban liveability [16]. Closer inspection also suggests that the form and fabric of cities and their built environments holds a key to delivering high levels of liveability but at markedly different levels of resource consumption and GHG emission: the cluster of low density car-oriented cities in North America and Australasia stand in marked contrast to Europe’s more compact transit-oriented cities. From both an environmental and global social justice perspective [17] the challenge for Australia is to dramatically shrink the EF of their cities by fundamentally re-shaping and re-designing their built environments and associated social practices, while maintaining liveability. Cities in developing countries such as China are growing rapidly, as is population wealth and EFs (WWF 2014). A key question is which city planning strategy will cities such as China follow? Some suggest they have been following the North American model [18] while more recently, some commentators are suggesting a shift to more compact, mixed use, and public transport-oriented development [19].

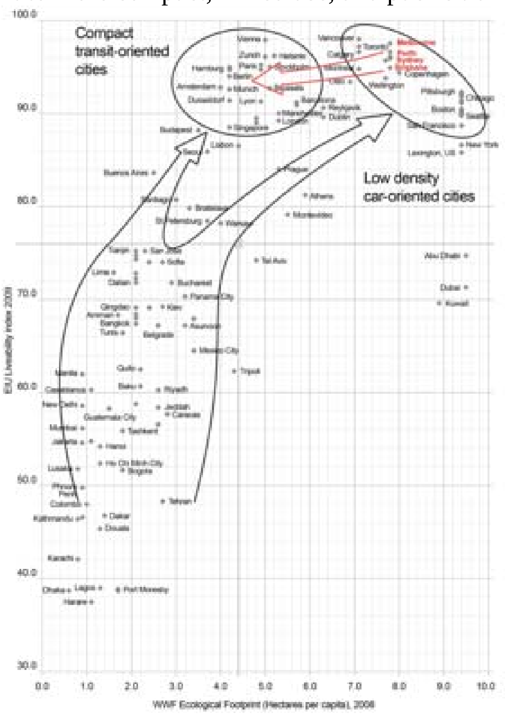

Fig. 1 Liveability-Sustainability nexus [Source: adapted from 20]

Clearly, radical reductions are required in the EFs of built environments in developed countries in the first half of the 21st century if sustainable low carbon societies are to be realised. Indeed, it has been indicated by CSIRO [20] that *peak CO2* must occur within the next decade if IPCC scenarios for a 1.5-degree centigrade temperature increase by 2100 is not to be exceeded. In this context, cities have been identified by the UN [21] as a source of up to 70% of GHG emissions (and by others even higher [22]). Significant variability exists between cities [23] as well as within cities [24] in relation to carbon emissions. The most critical transition of the 21st century involves the decarbonisation of cities, otherwise other critical urban transitions (see Figure 2 and below) will be stalled as a result of having to deal with the more chaotic futures associated with the disturbance and in some regions collapse of those systems that support cities; e.g. food supply, water supply, human health etc. [25]. The prospect of synchronous failures also arises due to the interconnected nature of 21st century cities [26]. In this context, then, the transformational changes that need to occur have been identified as:

- reduction in use of *natural resources* -- dramatically shrinking ecological footprints in high income developed societies by dematerialising industrial and construction processes and by enabling developing countries' ability to leapfrog the Kuznet's curve in the adoption of leading eco-efficient technologies.
- reduction in *emissions and waste streams*, with particular focus on decarbonisation of energy, stormwater and wastewater treatment and re-use and zero-waste pathways for industrial, construction and domestic sectors
- substitution of *smart and regenerative urban systems and processes* for those currently in use to achieve more effective economic, social and environmental planning and management of cities
- improvement in *urban environmental quality* of the public realm (e.g. waterways, green space) as well as responding to the environmental stressors associated with intensified urban retrofitting of private property
- improvement in *liveability and well-being* across the entire metro region
- progress in developing *resilience* in cities to the array of exogenous and endogenous pressures now evident.

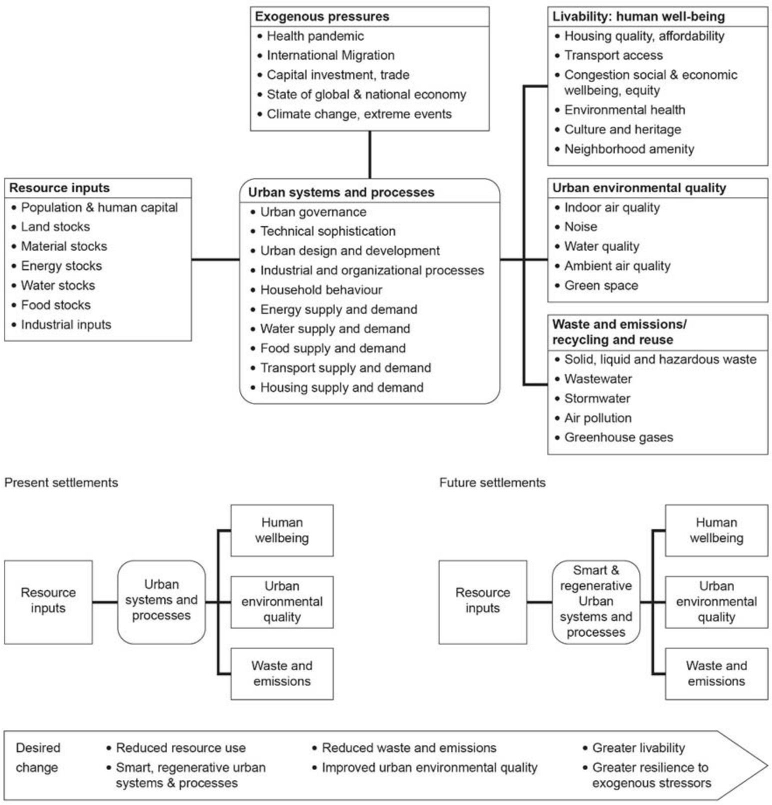

Fig. 2 Extended urban metabolism model of human settlements
[Source: adapted by author from 27]

The focus of the remainder of this paper is on transition pathways that have a capacity to significantly decarbonise key sectors of an urban system. Local and global drivers elevate the priority of this transition. The transitions required are socio-technical in nature, involve new technologies, innovative urban design and governance and behaviour change [1,16, 28]. The solution space is multi-scale, mirroring the range of challenges identified. This paper will focus on a range of interventions capable of decarbonising built environments -- on multiple levels.

2. Where to intervene?

There are multiple entry points for sustainable low carbon built environment innovation. They can be aligned to the concept of a series of carbon mitigation wedges [29] each capable of significant reduction in $CO2$ emissions. The challenge is for policy-makers to decide which wedges are preferable and how to direct effort and investment in these areas.

2.1 Mitigation and adaptation

Given the enormity of the actions required to address climate change, there has been a tendency to adopt separate lenses for mitigation and adaptation in respect of research, policy and the development of planning instruments; e.g. the CRC for Low Carbon Living was established primarily for mitigation purposes, while the National Climate Change Adaptation Research Facility and the CRC for Water Sensitive Cities are more strongly focused on adaptation. At the 2016 UN Framework Convention on Climate Change's 21st Session of the Conference of Parties (COP21), however, *both* were recognised as key foci, elevating the status of adaptation on the global UN climate change platform (http://www.c2es.org/international/negotiations/cop21-paris/summary). This follows previous attempts in IPCC reports [30] to highlight a range of planning and investment decisions involving trade-offs or synergies between adaptation and mitigation; and being explicit about the consequences that mitigation actions have for adaptation and vice-versa (Figure 3).

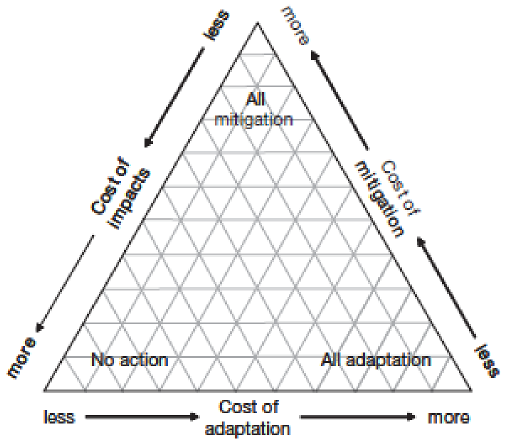

Fig. 3 A schematic overview of inter-relationships between adaptation, mitigation and impacts [Source: 30]

Sustainable low carbon urban development roadmaps need to include both mitigation (decarbonisation) and adaptation (resilience) pathways. One area of city planning where adaptation and mitigation issues are clearly connected relate to urban microclimates and the susceptibility of different built environment 'landscapes' to an intensification of urban heat island impacts under future climate change (e.g. increased episodes of extreme heat) and urban development (e.g. densification) scenarios. Options for cooling current urban environments by at least 2 degrees centigrade (an adaptation target) have implications for reducing energy demand for cooling buildings (mitigation target) as well as delivering human health co-benefits [31,32].

2.2 Carbon mitigation over the built environment asset life cycle

All built assets have a *life cycle* that extends from the stage at which it is conceived and its desired levels of performance specified, through planning, design, construction and operation, including facility monitoring and management until its end of life (at which stage de-construction/ re-use/retrofit/re-cycle/disposal options are evaluated). Yet to be widely implemented are policies and practices directed towards minimising an asset's carbon footprint (as well as its cost) over its life cycle. Also lagging are scientifically validated and government endorsed instruments (data and tools) capable of life cycle eco-efficiency assessment at material/product, building and precinct scale, despite multiple efforts [33,34,35] -- see also Section 3.

2.3 Carbon mitigation across the Asset/Infrastructure Supply/Value Chain

Closely related to the asset life cycle is the *supply chain* associated with the process of delivery of a particular built environment asset. Here focus is on optimising decision-making at every stage of a project's *procurement* and recognising that leadership and commitment to purpose is required on the part of all stakeholders, beginning with the asset owner/manager (client), and involving designers, constructors, material suppliers and facility managers across the supply chain. Governments overseas [36] and in Australia [37] have created frameworks for enabling low carbon supply chains for infrastructure procurement, but take-up is yet to occur. Tracking carbon flows in local and global supply chains and emission trading schemes more generally is a newly emerging area of research [23,38].

2.4 Sectoral carbon mitigation based on technology transitions

The scale of the decarbonisation challenge is now such that change must be transformative, not incremental. For cities this will require regenerative change to their critical sectors of operation [39], enabling what Birkeland [40] has termed 'eco-positive' development. Retrofitting of cities and their infrastructures becomes a core part of this process [41,42]. Here cities need to be able to draw from a pipeline of innovative technologies, products and processes that can be substituted when existing applications show signs of failure to perform at required levels. The volume of innovative technologies available for urban system transitions is large and is best represented by three horizons of technological innovation [27,43]. When all three horizons of technological innovation are harnessed and the formidable sets of barriers overcome [44,45] transformative changes can be realised:

- Energy transition: from a fossil-fuel based economy to one based predominantly on renewable energy sources, linked to distributed generation to form a hybrid system with centralized generation within a national grid.
- Water transition: from a centralized divert-use-dispose system to a hybrid, integrated urban water system which incorporates decentralised stormwater and recycled waste water collection as additional sources of supply.
- Waste transition: from a system originally predicated on resource extraction–manufacture–use-dispose to a circular economy based on industrial ecology and life cycle principles (waste=resource), cradle-to-cradle manufacture and construction; and an associated de-materialisation (and de-carbonisation) of the economy.
- Communications transition: from an era of low bandwidth analog systems supporting transmission of voice, data and low resolution images to a wireless, high bandwidth digital internet and mobile communications environment supporting global telepresence and an 'internet of things' capable of radical shifts in the mode by which a wide range of urban services are delivered (e.g. transport services, social services, health services, employment, retail etc.) with attendant carbon savings potential.
- Transport transition: where multiple transitions will be realized, including replacement of petroleum-based automobiles with hybrids and solar-electric or solar-hydrogen vehicles; intelligent transport systems and autonomous vehicles to optimize local and inter-modal transport and minimize urban traffic congestion; car sharing services; and (truly) integrated urban land-use-transport planning centred on active transport

(public transport, walking and cycling) ; and high speed rail for inter-regional travel as well as incorporating provincial cities into large functional metropolitan agglomeration economies.

- Building and construction transition: from buildings that satisfy a limited number of performance criteria centred principally around safety and minimum first cost solutions, to eco-efficient buildings whose life cycle performance is assessed on multiple levels virtually at design stage, is manufactured off-site and assembled on-site and whose ongoing operation and maintenance and dis-assembly is optimized via building information models.

2.5 Sustainable consumption and production: meshing demand and supply side innovation

Akin to earlier comments related to mitigation and adaptation, sustainable low carbon production and consumption are broad issues that generally represent separate areas of focus in the research literature as well as policy, with a few notable exceptions involving policy-based UNEP and OECD studies [46,47]. In a narrower context of energy supply and demand there are a greater number of studies and agencies involved, ranging from the Australian Energy Regulator responsible for national oversight of energy generation and distribution in the context of current demand, to local markets associated with specific energy wholesalers (representing supply) and retailers (representing demand), where government competition policy has resulted in a significant segmentation of this sector. With the increasing injection of renewable energy (RE) into the nation's grid (driven by a range of national and state RE targets established by governments), planning for a secure low carbon energy future is a current priority in Australia. From a built environment perspective, over the past decade the exponential take-up of rooftop solar PV in Australia has begun to significantly decarbonise the residential sector – especially in the low density suburbs where detached housing provides a ready-made vehicle for local area electricity generation [48]. This has left medium density housing and inner city/CBD precincts with a challenge of reducing the carbon in their electricity supply. The challenges here are related more to governance than to technology issues, however [49]. Challenges also relate to a need for improved forecasting of future demands for energy at precinct scale in a rapidly changing built environment (greater building densities as Australian cities make the transition from suburban to urban fabric) and demographic environment [50]; and how best to match these changing demands to an increasing palette of distributed generation and storage systems [51].

2.6 Built environment scale

The built environment can be represented by different *spatial scales* for purposes of exploring alternative pathways for delivering more sustainable low carbon outcomes from the planning, design and management of cities. They typically include: individual materials (products), buildings, precincts and entire human settlements (ranging in size from suburb to towns, cities and mega-metropolitan regions). While all are linked as part of a complex urban system, each built environment scale has important and unique challenges and opportunities linked to the decarbonising of cities (Fig. 4). This constitutes the focus for the remainder of this paper.

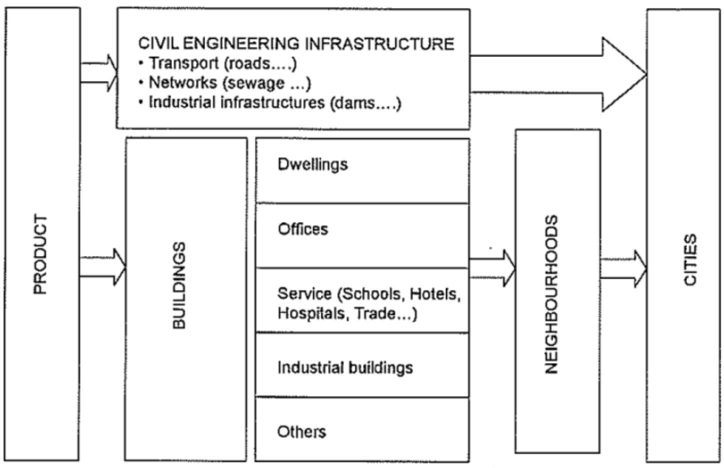

Fig. 4 The urban sustainability framework: products, buildings, infrastructure, neighbourhoods and cities [Source: 52; derived from ISO/TC

59/SC 17/N 172, 2005-11-02, ISO/CD2 15392, ISO /TC 59/IC 17/WG 1 (doc N041) Sustainability in Building Construction – General Principles]

3 Individual material products and their embodied energy (carbon)

The building blocks of a built environment are the material products involved in their construction. Each material and product has an environmental signature linked with the inputs to their manufacture, transport, assembly and service life (e.g. energy, water, emissions etc.). *Embodied carbon* is among the more significant of these product attributes requiring disclosure/product labelling in an era when decarbonisation of the built environment is being recognised as a key focus in global/national mitigation programs. For more than 20 years' Australian governments and industries have consciously avoided this component of built environment performance, preferring to focus on operating energy efficiency [53]. We are, however, approaching a juncture where the scale of improvements in the operating energy of buildings – as a result of the introduction and ratcheting up of energy ratings for new construction over a decade ago – is beginning to equate with embodied energy, over the life cycle of the building [54]. As such, it needs to feature in next generation energy/carbon assessment models for new building design and construction.

Energy/carbon is but one element among dozens that comprise life cycle assessment (LCA) of materials, an applied research activity extending back decades. A recent assessment of LCA in Australia [34] reveals that activity and information is fragmented among several databases and providers, reflects multiple methods (input-output, process models and hybrids; cradle-to-cradle vs. cradle to gate etc.), and sufficient levels of open access for purposes of validation and comparative analysis. A focus on embodied carbon may be the catalyst needed to produce a national, scientifically validated database for use in life cycle assessment of carbon in the built environment – equivalent to the National Pollutant Inventory [55,38]. Without such a data platform, automated assessment tools for buildings [33], infrastructure (IS rating systems; www.isca.org) and built environment supply chains more generally will flounder and lack authority.

4 Building scale innovation

There has been a significant level of research and innovation associated with decarbonisation of buildings, which suggests that pathways for delivery of zero carbon buildings are becoming well known – if not implemented. Avenues for minimising embodied energy and carbon in buildings have been identified, and a combination of BIM tools and LCA (or more focused embodied carbon) databases represents the platform from which informed design and assessment can be undertaken. Unfortunately, there continues to be a lack of political will – in Australia as well as in other countries – for actively pursuing a life cycle approach to building energy and carbon performance rating. Operating energy performance and energy efficiency has been the principal focus of public policy and building regulation in Australia for the past decade. Research on the energy efficiency of the different components of buildings – their shell, built-in appliances, plug-in appliances, floor size and floor plan, as well as position on site – all have contributions to make to amount of energy consumed. When combined with renewable distributed generation and storage, the pathways to zero carbon or carbon neutral buildings can be mapped (e.g. diagrammatically in Figure 5). Routes to decarbonisation for new housing have been empirically modelled and found to be straightforward and affordable – requiring the minimum current energy rating standard for the shell, energy efficient appliances and rooftop solar PV [41,48]. Housing built before the introduction of the national energy efficiency rating scheme in 2004 would need to enhance their energy efficiency accordingly via retrofit before being able to achieve carbon neutral status.

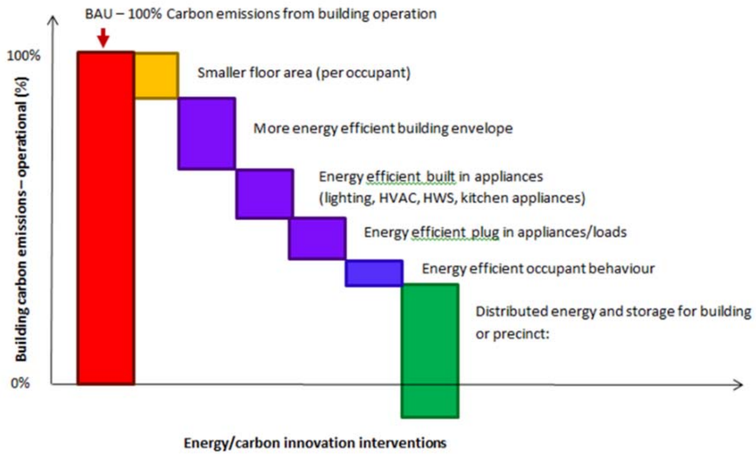

Fig. 5 Pathways to decarbonising building operations

A number of studies related to buildings and energy, however, have identified significant gaps between level of dwelling energy efficiency rating 'as designed' compared with 'as operated' [17]. Explanations for this gap can be found in relation to the 'as designed' versus 'as built' gap – a failure of government auditing of new construction [56]. Also, an 'as built' versus 'as operated' gap can be seen as reflecting a significant difference between household (conservation) attitudes and intentions towards energy use and low carbon living and their actual behaviour – an 'attitudes-behaviour' gap [57,58,59]- see Figure 6. There are multiple drivers of household energy consumption (structural and cognitive, social practice and social values), but it is clear that there can be no carbon living without a low carbon built environment -- the context in which behaviours are shaped and constrained [60].

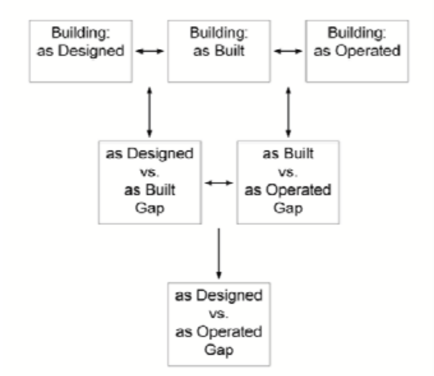

Fig. 6 Gap analysis for design, build and operate

5 Precinct scale innovation

Precincts constitute the critical operational scale at which a city is assembled (greenfields), is re-built (brownfields, greyfields) and is operated (where residents spend large proportions of their day either in domestic or workplace settings). They are the 'building blocks' of our cities [61] and represent the scale at which urban design makes its contribution to city performance. Precincts constitute the origins and destinations for homes, schools, workplaces and recreation and the trip generators associated with connecting each. In aggregate, they are a microcosm of urban life. It has been argued, however [62], that the unsustainable nature of today's cities is due in part to poor planning at the neighbourhood level. For example, the high levels of car usage and traffic congestion are a reflection of an absence of: mixed use development, variety in housing types, especially medium density, and lack of walkability and public transit access having been designed into urban neighbourhoods in recent decades [63,64]. Purely in CO2 terms, variability in the housing and transport attributes of different suburbs means that neighbourhood-scale carbon emissions can vary by as much as 50% across Australian cities [54,24]. Precincts constitute a critical focus for the achievement of any strategic planning target for cities (eg. more compact, with 70+% of new housing as infill; more walkable, carbon neutral, water sensitive, etc.) since this is the scale at which an optimal combination of urban design innovation, urban technology innovation and behaviour change can jointly occur. It is in this context that assessment of built environment precincts in relation to their carbon neutrality status has recently emerged as a policy instrument for carbon mitigation at federal government level [65,66] following recommendations in CRC for Low Carbon Living's Precincts Scoping Study [34].

Cities provide three distinctively different urban arenas for precinct design and development: greenfields, brownfields and greyfields. They are characterised by their contrasting built environment fabrics and varying receptivity to different forms and models for property development and redevelopment (see Figure 7) [67,68]. The shift in Australian capital city planning strategies to more compact cities involving a more intensive retrofitting of established suburbs – in Australia involving a significant transition from an essentially low density 'suburban' built environment to one which is of higher density and more 'urban' in character – has created a need for more effective and innovative urban planning and design processes to achieve these outcomes, particularly in the brownfields and greyfields.

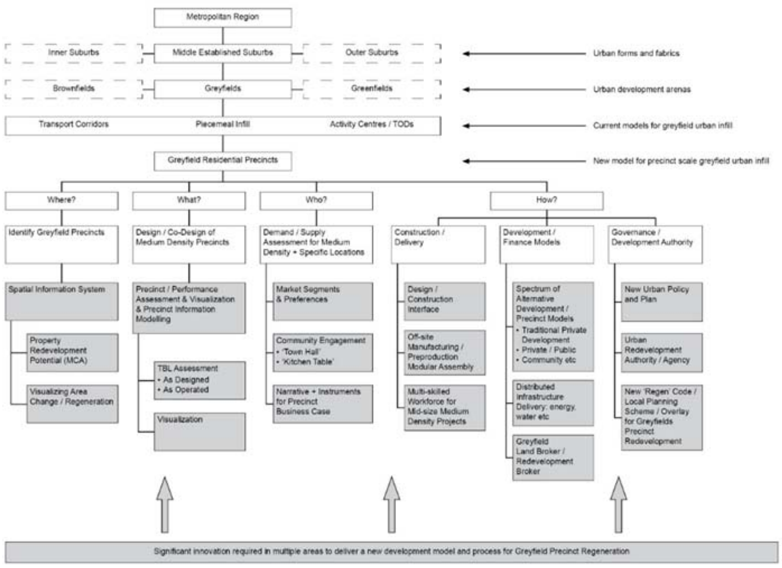

Fig. 7 Development arenas for Australian cities
[Source: Adapted from 72]

5.1 *Brownfield precincts*

Brownfields constitute abandoned or under-used industrial or commercial sites associated with an earlier era of economic activity. Typically, they include the docklands precincts that served the sea trade prior to containerisation, outdated commercial high-rise buildings, abandoned manufacturing sites, sections of railways, vacant petrol stations, formerly viable retail sites etc. They are generally owned by a single party, usually government or industry; of a scale which is closer to that provided by greenfield sites for development; contaminated to some degree, depending upon the nature of prior use; and unoccupied, obviating the need for community engagement at a level required of greyfields. Docklands, as with many brownfields precincts, represents a cautionary tale of opportunities lost in precinct scale regenerative urban renewal. Until recently, Docklands represented the largest brownfield development initiated in Melbourne. It is a 150ha site adjacent to the CBD and is expected to accommodate 20,000 residents and 80,000 jobs upon completion in 2025 (http://www.places.vic.gov.au/precincts-and-development/docklands). Construction commenced in 1997 after a chequered and still controversial period of planning undertaken by the state government urban renewal agency, VicUrban, which consisted of dividing the large site up into seven land parcels which were then put out to tender to property developers. Initially excluded from the planning, design and development process, local government (City of Melbourne) are now involved in attempting to 'retrofit' the area with those basic elements associated with place-making following the July 2012 transfer of development responsibility from the state government Docklands Authority. While successful in facilitating development of predominantly commercial buildings and high-rise apartment blocks at Docklands, the quality and innovativeness of the outcomes has been the subject of repeated criticism, predominantly for being overly market driven and un-coordinated and especially for omitting public realm provisions such as green space, good pedestrian connections aligned with active uses, community facilities including schools, and cultural activities at the expense of site yield. A 'carve-up' of land among major developers in the absence of any plan for introduction of distributed infrastructures – energy, water and sewerage and waste principal among these -- capable of operating at precinct scale meant a lost opportunity for creating a more self-sufficient, resilient, low carbon water sensitive and regenerative built environment. Lessons learned need to be translated into the planning process for the next major brownfield development adjacent to Docklands: Fisherman's Bend.

Fishermans Bend is a 260-hectare site adjacent to both the Melbourne CBD and Docklands, where current industrial land use has been rezoned for mixed use redevelopment in order to accommodate a projected 120,000 (and on some estimates 240,000) people and at least 60,000 commercial jobs. The Government of Victoria [69] has established a strategic framework for its development over the next 40 years that clearly identifies a set of sustainability objectives: low carbon, water sensitive, climate resilient, low waste and liveable (analogous to VicUrban's attempts at identifying ESD principles to guide development at Docklands; [70]). Since the release of the Framework document there has been a change of state government, and this often foreshadows change in planning priorities. It is at the initial planning stage of a major brownfield retrofit project that innovative infrastructure and building options need to be identified and modelled in order to realise the life cycle benefits capable of being captured by the built environment. In an attempt to explore potential urban design innovations, Australia's two urban-focused Cooperative Research Centres undertook a joint study of energy and water options [71]. From a resource perspective, the additional water and energy inputs to a precinct such as Fishermans Bend is substantial, if delivered in a traditional manner (as was the case with Docklands); for example, if all water is imported, a precinct of 120,000 residents is estimated to need approximately 11,000 ML/year, and if all buildings are designed to current standards, then additional electricity required is approximately 3GJ per year and if sourced from the grid would require additional power station capacity of 220MW to supply the precinct's peak demand. By introducing a number of water sensitive design innovations related to stormwater capture, rainwater harvesting and greywater recycling – all of which can be directed to non-potable uses within the precinct and its buildings – the volume of imported water can be almost halved. By mandating that all buildings be designed to world best environmental rating standard (compared to local minimum), over 40% reduction in annual energy demand and carbon emissions is achievable, and greater if low or zero carbon precinct scale distributed generation systems were also employed. The governance of Fishermans Bend redevelopment will be what proves critical in whether it becomes a showcase for brownfield precinct regeneration or a repeat of business as usual developer-led/ project-led development.

5.2 Greyfield Precincts

Greyfields lie predominantly between the booming CBD and inner city housing market and the more recently developed greenfield suburbs, providing significantly greater access to employment, public transport and services than the latter zone. Greyfields in the Australian context have been defined as those ageing but occupied tracts of inner and middle ring suburbia that are physically, technologically and environmentally failing and which represent under-capitalised real estate assets [68]. To date, greyfield infill redevelopment has been occurring in three urban settings (again see Figure 7):

- *Activity centres*, range in size from the CBD, and include several principal activity centres characteristic of poly-centred development in large cities (i.e. major retail and commercial activity centres located within the 30 or more municipalities in Melbourne and Sydney) and a myriad of neighbourhood centres. They have been a central plank in Australia's metropolitan planning schemes for decades and in more recent times have featured in attempts to further intensify growth around transport oriented development of activity centres - the ’20 minute cities within the city’ [73]. The activity centres have been zoned as growth precincts in an attempt to attract high density development.

- *Major transport corridors* are a more recent proposal for greyfield redevelopment, identifying linear transport corridors as an additional focus for medium-rise high-density development. The requirements for this to work are set out by Adams et al. [74] and include prescriptive controls over key aspects of corridor development, including up-front ‘as of right’ development to levels of between four and eight storeys. Key drivers advanced by the proponents of this model, in addition to providing a pathway for delivering a significant volume of net new housing in greyfield areas (as a result of enabling land value for redevelopment to be more easily determined), include the removal of development pressure off the existing interstitial suburbs which enables them to act as the ‘green lungs’ of cities (enhanced water, energy and food production etc.) at their existing levels of low density. As with all greyfield redevelopment initiatives, a key challenge is achieving public acceptance among local residents. The principles outlined will assist in this regard, since they are intended to help assure the wider community that these corridors are fixed and will not spill over into adjacent suburban areas. Decanting residents from their cars in these locations will remain a challenge however [75].

- *Fragmented infill* represents the majority of housing redevelopment currently occurring in the greyfields. It typically involves the construction of between one and four new dwellings on an established ‘knock-down rebuild’ site where the value of the land accounts for 70-80% or more of the value of the property asset prior to its redevelopment. It represents sub-optimal redevelopment in many respects in that it generates a relatively low yield in terms of net new housing, and represents a slow burn on the local, public urban resource base: there is loss of (private) open/green space with the removal of gardens and lawn typically part of older detached housing; additional population adds to the demands on municipal services; more households currently means more cars and added road congestion- in the absence of more public transport services or car sharing; and the scale of redevelopment usually means that the project does not attract a developer contribution that can assist government in redressing the associated negative externalities.

An extensive assessment and critique of current greyfield infill redevelopment in Australia is found in [68,72,76,77]. Principal findings (for Melbourne) were:

- Patterns and scale of dwelling development differed significantly between the brownfields and greyfields: close to 80% of greyfield infill projects are 1:1 (27%) or 1:2-4 (50%) – i.e. relatively low yield knock-down-rebuild developments adhering to current planning and building guidelines. Brownfields are the focus for higher yield (apartment) projects: 1:50-100 (17%) or 1:100+ (56%). There is a significant infill gap in the intermediate medium density dwelling range (ie. Projects of 5-50 units) – the ‘missing middle’ - where greyfield precinct redevelopment is most prospective.
- Proximity to major transport routes were not an automatic determinant of level of infill. Percentage of net dwelling infill in Melbourne is evenly spread between high, medium and low public transport access zones, reflecting that households remain attached to their cars and property developers are persisting with providing (often dual) car parks in locations well positioned for public transit.
- Activity centres to date have not been attracting significant levels of infill housing except in the CBD (currently representing 80% of all activity centre infill; high rise construction fuelled significantly by foreign investment in new apartments).

Most greyfield infill housing redevelopment is currently occurring as fragmented development that is largely located outside of local and state government designated redevelopment areas and is not contributing the ‘dividend’ it might to the regeneration of Australia’s cities if a precinct scale retrofitting was pursued as an urban development policy.

5.3 Greyfield precinct regeneration

Greyfield residential precinct regeneration is the focus of a large socio-technical urban transition project (*Greening* *the Greyfields*; http://www.geospatialworld.net/article/the-story-of-greening-the-greyfields/ ; funded by the Co-operative Research Centre for Spatial Information since 2011) that is attempting to formulate, test and apply a new model for urban regeneration in the established middle suburbs of Australian cities. The initial study [72] explored how infill redevelopment could be undertaken more effectively on a precinct basis in order to contribute to meeting a range of strategic metropolitan planning objectives. It involved a series of facilitated workshops with 70 leading built environment thinkers over a 12-month period with the objective of articulating the basis for a new development model for greyfield precinct regeneration. The study revealed that the greyfield residential precinct regeneration approach is desirable and feasible, but a number of barriers would need to be overcome for successful implementation. Much of the innovation needed was found to be organisational and institutional, supported by some technological innovations. Figure 7 identifies the areas (shaded) where major innovation and change needs to occur to achieve a new, viable development model for greyfield residential precinct renewal:

- *Where?* Identifying the most prospective locations that developers and planners should target for precinct redevelopment; requiring the creation of new geospatial tools [28];
- *What?* Improvements to the design processes needed to achieve innovative and affordable medium density housing, integrated with distributed technologies for energy, water and waste for more sustainable, low carbon living; establishing an attractive ‘future urban character’ for medium density housing in the middle suburbs; involved creating new tools for assessment of regenerative performance and benefits of precinct design [72,78];
- *Who?* understanding the nature of demand for medium density living in the middle suburbs; developing new ‘kitchen table’ engagement processes that can facilitate citizen-led land assembly between neighbours [79];
- *How?* creating new planning instruments to support precinct scale redevelopment in established suburban areas (viz. greyfield precinct development overlays); new brokers and developers for greyfield precinct renewal; application of modular construction and assembly processes capable of introducing efficiency and quality benefits; application of distributed energy, water and waste technologies to enhance precinct environmental performance [5].

In *Plan Melbourne Refresh* [80] a recommendation has been made that Greyfield Precinct Renewal be proposed as a new planning objective for the 2016 Strategic Plan for Metropolitan Melbourne. It provides a validation of the benefits that precinct-scale regeneration could contribute to the sustainable low carbon development of Melbourne. Precinct regeneration – compared to KDR/ lot-by-lot (building scale) redevelopment -- offers the prospect for the (re-) *design* of more sustainable, resilient, low carbon neighbourhoods: housing (yield, variety, affordability); energy (low/zero carbon; distributed generation and storage); water (integrated stormwater/ rainwater/ greywater; water sensitive design); waste (optimise recycling, food composting); mobility and health (more walkable, less cars, car sharing); green space (maintain rather than lose); neighbour contact (new community spaces, shared gardens) – congenial density.

6 Metro scale innovation

At metropolitan level, integrated city scale planning of land use and transport (LUT) represents a first step in any process that aims to deliver more sustainable urban development, since it establishes the envelope within which finer levels of urban design occurs – typically at precinct scale. The principles of large scale LUT planning have been established for at least half a century [81], but despite the national significance of cities as ‘engines’ of modern economies and places for people to live, there has been massive under-investment by governments in the development of the instruments necessary to underpin the planning and management of these large, dynamic complex systems. In Australia, a succession of neo-liberal governments has progressively hollowed out and marginalised their in-house expertise, with the result that ‘city planning’ in recent decades has become increasingly developer-led. As a consequence, environmental and equity considerations have been relegated in significance as outcomes. There are significant ‘planning deficits’ requiring attention.

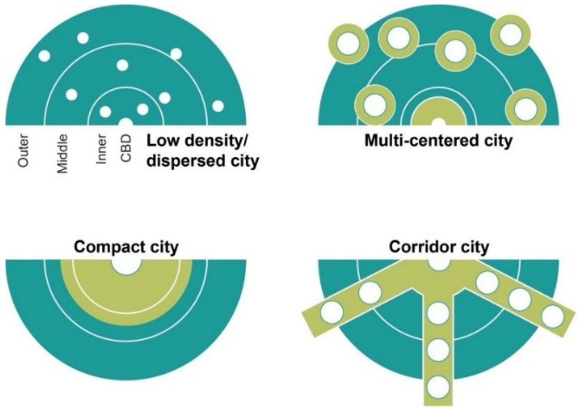

Fig. 8 Archetypal urban forms for LUTE modelling

The urban land use-transport-environment (LUTE) modelling undertaken for the Academy of Technological Sciences and Engineering and the federal government [82,83] represented a pioneering Australian attempt at exploring the nature of the link between urban form (transport networks and associated travel patterns, location of housing, location of jobs, population distribution and density) and environmental performance (energy use, GHG emissions and urban air quality). The modelling assessed four archetypal urban forms (Figure. 8) – dispersed low density city, multi-centered city, corridor city and compact city -- in the context of future scenarios of population growth, employment and housing distribution and transport infrastructure investment (see [84] for detailed descriptions of scenarios and assumptions). Low density suburban greenfield development (the 'business as usual' scenario characteristic of the most recent era of urban development) was the worst performer across all indicators. The compact city (bulk of new population and jobs located in the established public transport-rich inner and middle suburbs together with associated transport infrastructure investment) performed best in terms of transport-based energy consumption and CO2 emissions: a reduction of more than 30% in energy use and GHG emissions compared to low density sprawl. Reductions in total transport CO2 emissions compared to the 'business as usual' scenario were also lower for all other urban forms (see Table 1).

Table 1: Percentage improvement in CO_2 emissions compared to 'Low Density/Dispersed City' scenario [Source: 82]

Future urban form scenario	Reduced CO_2 emissions from transport (%)
Compact city	31.5
Multi-centred city	21.7
Corridor city	15.5

The take-home message from the LUTE study was that intentional planning of and investment in a city's public transport and associated road infrastructures together with coordinated housing and employment development downtown, in established low density inner and middle ring suburbia ('compact city'), in corridors or in key district centres delivers substantial benefits compared to laissez faire market- 'led' urban development where individual 'projects' (mostly knock down rebuild) are optimised from a financial perspective, often at the expense of the wider urban system's performance. Subsequent urban form studies have confirmed these findings [54,85,86,87,88].

7 Conclusions

A stage has been reached in 21st century urban development where government policy-driven change of a type and scale not witnessed in Australia for a generation or more is required to address the tsunami of challenges that confront the nation’s cities. Foremost among these is decarbonisation. For this to occur there must be regenerative (re)development of our built environments. There are multiple interventions possible – as outlined in this paper – and all require government involvement: federal, state and municipal levels. Markets can’t set policy, but they can deliver on policy. For the energy/carbon sector in general, and where it intersects with the built environment in particular, government policies have been uncertain and fluid (especially in relation to carbon pricing and renewables). Markets, and the industries that operate in them, do not react well to uncertainty, especially in relation to their long term planning and investment. Yet these are the sectors – energy, property and construction, and utilities – that are at the core of the next phase in post-industrial transition: to a green economy. And cities are at the heart of this transition [89].

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