Significance of global oil depletion to urban residential development

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Abstract

The global production of oil is predicted to peak in the first decade(s) of this century and decline, while demand outstrips the discovery and exploitation of new oil sources. Land use (spatial) planning has largely failed to address the full consequences of the accelerating impacts of post-peak oil demand and subsequent oil depletion, as they may affect planning future urban growth in the Australian and wider global context. This paper lays the groundwork for a PhD methodology that investigates oil dependency issues in the sustainable planning context, based on a literature review, to establish relationships linking direct and indirect oil related inputs to urban land development and residential construction.

The literature review failed to reveal conclusive information–beyond embodied energy in building materials and energy efficiency in ‘green building’–or theories about how future oil supply constraints may affect the feasibility of urban land development and residential building construction.

The conclusion to the literature review is that urban planning is based on the underlying assumption of a business-as-usual approach to urban residential development, albeit with higher prices for petrol consumption in transport.

The research points to a hypothesis that relationships linking oil related inputs to urban residential development suggest some current forms of development in the Australian and wider context may become unsustainable in a future with globally constrained oil supply (this will later extend to gas supply).

The urban metabolism model indicates the broad relationships, but not relative oil vulnerabilities of urban development, or the mitigating factors. Further case study analysis of material flows of oil related inputs for a representative residential typology will assess how future oil constraints may affect urban residential development and how to adapt it to more viable urban forms.

Keywords: cities, oil depletion, peak oil, sustainable construction, urban form.

1 Introduction

The Twentieth Century has been the era of abundant supplies of petroleum and the dominance of the private motor car (automobile). Cheap petrol (gasoline) has been the most important catalyst for expansion of cities into amorphous suburbs and beyond, mainly in the form of low density detached houses, particularly in developed nations such as Australia and the United States of America (USA). The urban form of once compact cities has bloated into sprawling car dominated metropolitan regions. The era of cheap oil may end in this decade, as demonstrated by the Association for the Study of Peak Oil and Gas [1], IEA [2] and others [3, 4].

The imminence of global peak oil prompted a PhD investigation of the relationship between oil constraints within the current planning horizon and urban residential development in the Australian context; and the built environment factors affected by future oil depletion that might flow from such a relationship.

2 Urban sprawl to 'auto city'

In his history of sprawl, Bruegmann [5] charted the progress of suburbs in Europe and USA from the Roman period to the present. Prior to the motor car era, however, cities remained essentially walkable and horse carriage enclaves. In the Twentieth Century inter-war years, an acceleration of outward movement of both residential and industrial development led to an explosion of the urban land areas in Australian, USA and some European cities as suburban sprawl.

Later gentrification of the core of cities led to a bi-directional flow of people, and many neighbourhoods were changing in ways not explained by simplistic static models of dynamic urban form and growth, such as the classic Park and Burgess model of Chicago, the modified Hoyt's sector diagram, or the Harris and Ullman Multiple Nuclei model [6].

Rail and tram transit routes in the residential and manufacturing corridors of transit cities influenced the structural form. The later ill-defined form of the multiple nuclei model reflects the transition from walking and transit cities to what Newman and Kenworthy [7] termed the 'Auto City'. The freedom of the private car led to infilling between rail and tram routes, extending urbanisation for those who could afford such personal mobility to some 50 kilometres (about 30 minutes driving time) from the employment heart.

Forster [8] noted 'only cars could connect low-density suburban homes to jobs, schools, universities, health services, and entertainment venues that were themselves increasingly located in other suburban locations, served poorly–if at all–by public transport'. Bogart [9] also argued that urban living is a 'complex web of relationships' that necessitates multiple cross town journeys for day-to-day activities and leads people to abandon inner city amenity and mass transport for decentralised living with the 'convenience of personal transport'. Hence, low density suburban sprawl is the heritage of the car in the Auto City.

However, oil constraints will affect the viability of outer suburban living with rising fuel prices, initiating an accelerating trend back to compact urban form, and encouraging more sustainable lifestyles in walkable neighbourhoods.

3 Sustainable Urban Development

3.1 Managing Australian urban growth

The dichotomy of inner or outer city living leads to consideration of future forms of sustainable urban development and growth management. Since the 1970s, the town planning and related professions have sought to control and manage the growth of cities, limit peri-urban sprawl and address the problems of informal settlements in both the developed and developing world [10]. The Australian population [11] is predicted to grow from 22 million in 2008 to the order of 35 million by 2056, which will be accommodated mainly in existing large cities. In the capital cities, accommodating an estimated 10 million more urbanites in this period is similar to the growth during the whole of the Twentieth Century.

All major Australian cities have been subject to planning schemes and more recently to growth management strategies, which introduced systematic land use regulations, although suburban sprawl has generally continued in the spread of city footprints. The more recent town plans all emphasise planning responses to climate change and in that context seek to promote public and active transport to reduce greenhouse gas emissions from transportation. Yet until 2010, very few took into consideration an oil constrained future, beyond a reference to ‘rising oil prices’.

3.1.1 Perth and Melbourne growth management studies

Two studies published in 2009 highlighted the problems of managing population increase in the Australian capital cities of Perth [12] and Melbourne [13]. The Perth study *Boom Town 2050* challenged doubling the population from 1.5 to 3 million by 2050, requiring 700 000 new dwellings and reproducing the equivalent of the city’s entire infrastructure that was constructed over 179 years in 40 years.

Alternative *horizontal* urban scenarios for Perth are conceptualised as ‘POD City’ (contemporary urban villages), ‘Food City’, ‘Car Free City’, ‘Seachange City’, and ‘Treechange City’. Three densified *vertical* scenarios are categorised as ‘Sky City’, ‘River City’ and ‘Surf City’. These are synthesised in figure 1.

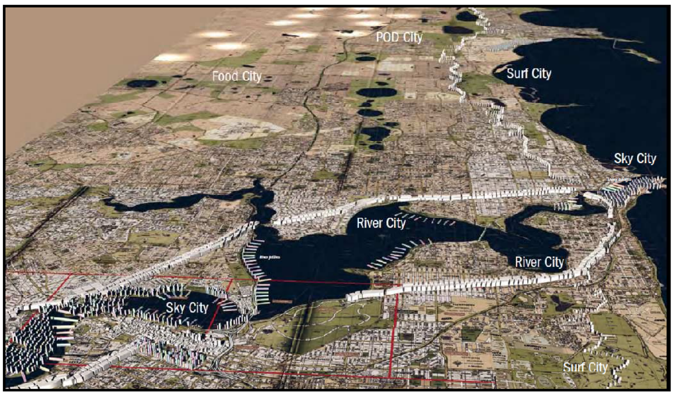

Figure 1: Perth development scenarios ([12] p.390)

Figure 2: Melbourne corridor development concept ([13] p. 28)

The Melbourne study *Transforming Australian Cities* examined the potential to transform the region for a projected population of five million by 2029. Accommodating some 840 000 people in 600 000 dwellings at 200 people per hectare–as infill development in activity centres and along transport corridors–takes into account climate change and diminishing fossil fuels. This approach was suggested as the means to direct growth by taking pressure off *ad hoc* redevelopment of existing suburbs. The corridor concept is shown in figure 2.

An essential weakness inherent in these and similar planning studies is that vulnerability to future oil depletion is becoming recognised in relation to urban transportation, and strategies–e.g. public and active transport–are proposed to mitigate its impact on urban mobility. Yet strategic planning scenarios assume a 'business as usual' approach to constructing urban infrastructure and the necessary facilities to support urban living. For instance, neither cited study is overtly cognisant of the fact that oil shortages in the post peak oil era (i.e. within the current 20 year spatial planning strategic horizon) could have a significant impact on the ability to construct the proposed medium-high density residential development, especially in compact high-rise transit oriented network city forms.

3.2 Paths to planning more resilient cities

The late 1980s saw a concerted promotion of urban consolidation by policy makers, linked to the concept of ecologically sustainable development (ESD). It is defined here adopting the 1992 Australian National Strategy for ESD:

> Development that improves the total quality of life, both now and in the future, in a way that maintains ecological processes on which life depends.

Theories about sustainable cities have tended to focus on 'new urbanism' mixed use development [14, 15]; the compact city form with 'smart growth' [16]; 'transit oriented development' [17]. A strongly renewed ecological emphasis is expressed in terms such as ‘eco-neighbourhoods’ [18], ‘urban villages’ [19], ‘eco-villages’ [20], ‘eco-cities’ [21], ‘cohousing’ [22] and ‘transition initiatives’ (which combine oil and energy descent with climate change resilience) [23].

Sustainability must embrace the concept of *resilience*, which has been adapted from ecology to spatial planning applications. It is relevant to both oil depletion and climate change adaptation. Newman *et al* [24] define it to mean:

> Resilient cities have built-in systems that can adapt to change, such as a diversity of transport and land-use systems and multiple sources of renewable power that will allow cities to survive shortages in oil supplies.

Yet Newman *et al* note that cities ‘now consume 75% of the world’s energy and emit 80% of the world’s green-house gases’. Whilst this is not all related to petroleum, transport alone accounts for between one quarter and one third of all energy consumption. The built environment must reduce its carbon footprint.

Consideration of alternative transport options suggests existing suburbs are likely to survive the interim post peak transition period, albeit subject to much higher private transport costs, if suburban communities make some degree of transition to a more resilient state. The degree of resilience would depend on:

- whatever alternative fuel, or electric powered vehicles are available;
- proactively increasing public transport patronage and active transport (walking and cycling) usage to more localised daily activities; and
- adopting localised sources of food and goods to reduce transport distances.

While the built environment of existing suburbs are constrained mainly by transport modes, future urban growth on the scales required is problematic.

3.3 Paths to more sustainable building development

Many, if not most, of the most influential published works warning about oil depletion and its effects have not been authored by planners, but by geologists, engineers, eco-social commentators, architects and eco-builders. It is mainly in alternative ‘green’ or ‘sustainable’ building and construction studies and guides that there is support for the natural materials and processes that could reduce oil dependency. Most focus is on low density detached houses and some alternative guides look backward to the pre-oil economy for inspiration [18, 25, 26, 27].

The most progress is being made through promotion of contemporary green building ratings by organisations such as BRE Global Ltd [28], LEED [29] and Green Building Council of Australia [30]. Whilst these ratings are not aimed specifically at resilience to oil depletion, they are doing so indirectly by the higher energy efficiency and lower embodied energy components of the ratings.

4 Oil dependency in urban development

4.1 Urban metabolism framework

Yencken and Wilkinson [31] made an extensive exploration of sustainable development in the Australian context. The authors suggested that ‘settlements as they are usually conceived are inherently unsustainable’ and addressed the issue

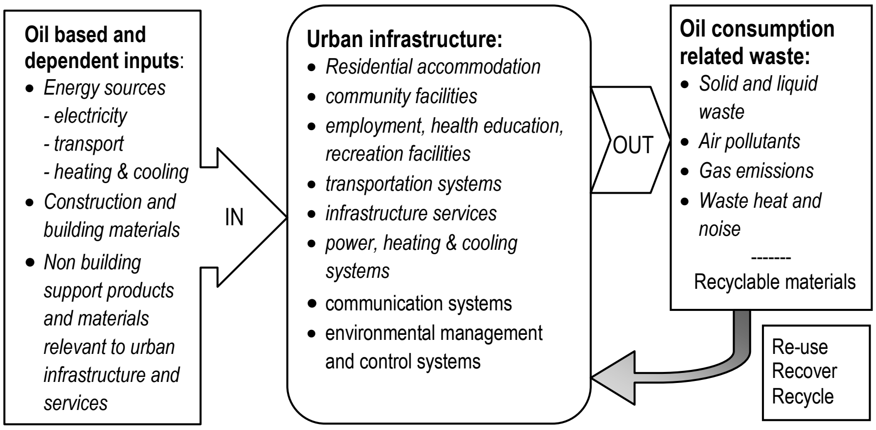

Figure 3: Oil related urban metabolism model

by using a conceptual urban metabolism framework. It is a useful starting point to construct a model of the role of oil in the urban ecology. Although only inferred in their model, oil features in the resource inflows for energy, materials manufacture and goods transport. The relationships are highlighted in a modified urban metabolism diagram at figure 3. While embodied and operational energy of oil (and gas) inputs are very important underlying aspects of urban metabolism, as shown by Hegger *et al* [32], they also include both direct and indirect feedstock inputs to land development and construction materials, as demonstrated by Calkins [33], and petro-chemicals. Wittcoff *et al* [34] show in detail that oil and natural gas are the main sources of seven chemicals, on which the vast organic chemical industry is based, producing materials ranging from asphalt to glues, paint, plastics (e.g. PVC in many forms, pipes, sheets, films, foams), rubber, sealants and solvents. Products of the oil based economy pervade the built facilities, transportation and infrastructure that supports settlement outcomes. Energy consumption and manufacturing processes also cause waste outputs, including liquid waste, air pollutants, greenhouse gases, waste heat and noise.

4.2 Oil supply constraint impacts on urban form

Estimates of embodied and life cycle energy use and material flows have been made by several agencies and research establishments. Metabolic impact analysis is used in a landmark European research project–the Sustainable Urban Metabolism for Europe (SUME) as proposed by Pinho *et al* [35]. As part of the SUME project, Weisz and Steinberger [36] made a wide ranging literature review of energy and material flows in global cities, concluding that 'buildings are the largest single sector in energy end use world-wide' when construction, maintenance, operational use and demolition (full life cycle) are taken into account. The SUME approach analyses the impacts of urban forms on resource use at city scale and proposes modifying the forms to reduce ecological footprint.

4.3 Key relationships between oil inputs and urban form

In contrast to SUME, this PhD research aims to assess the effects that reducing oil supply may have on the existing approach to developing urban forms. The key relationships of planning/design and construction are presented in figure 4.

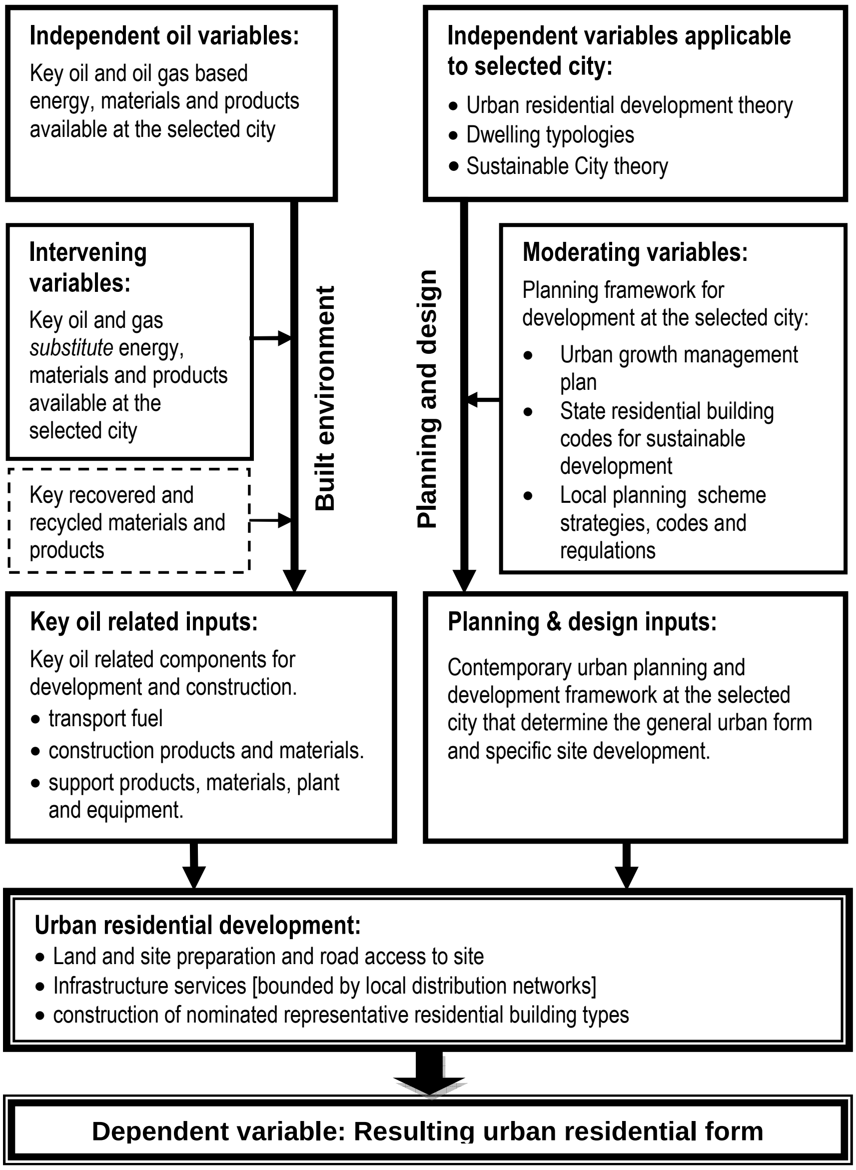

Figure 4: Key relationships between oil inputs and urban development form

4.4 PhD literature research conclusion

The conclusion to the literature review is that urban spatial planning is based on the underlying assumption of a business-as-usual approach to urban residential development, albeit with higher prices for petrol consumption in transport.

The detailed literature review points to a tentative hypothesis that:

Relationships linking oil related inputs to urban development suggest some current forms of residential development in the Australian context may become unsustainable with a future globally constrained oil supply.

Testing this hypothesis requires a complex methodology such as a partial life cycle inventory and assessment under ISO 14040. A similar form of analysis of urban metabolic oil related inputs, but more relevant to this research, is material flow analysis (MFA) described by Birkeland [37], Brunner and Rechberger [38], which examines the flow of material resources and energy from source to disposal through human or natural systems to trace a particular substance or material throughout a system, production process or supply chain.

It is intended to use a sub-set of MFA–setting analysis boundary conditions for inputs only–to trace oil related inputs to land and building development cases.

5 Urban residential development case studies

As the focus of this research is the main type of urban development–residential accommodation–the building typologies to be analysed are described below.

Australian residential development has a diversity of urban setting forms, largely based on historical precedent and particularly exhibiting a suburban, as opposed to compact urban form. While the urban form provides the development setting, buildings are the products of the technological design and construction processes, with varying amounts of quantities of renewable and non-renewable materials, each having different embodied energy.

Hence, each residential building type has a characteristic identity, also dependent on the manner of attachment (side-by-side or stacked), height, and floor area, which affects energy and material inputs, comprehensively described by Bokalders and Block [39]. Some contemporary building types above about three storeys are more reliant on technology and hence relatively more vulnerable the oil economy. Residential tower buildings have been demonstrated by Perkins *et al* [40] to have higher embodied and operational energy requirements, that offset the lower transport energy costs, as compared with two-storey units.

Hence the key interest in contemporary residential land development and building typology is that some types may be comparatively more vulnerable to oil deletion than others. If this is the case, it may affect the sustainability of some forms of new urban residential development in the medium to long term.

5.1 Urban residential typology and building elements

The contemporary urban residential typology relevant to this research and the subject of detailed case studies for MFA testing is broadly identified as:

A. Detached and semi-detached houses of one–two storeys on individual lots (the predominant suburban style);
B. Attached town (row or terraced) houses and walk-up apartments of two-three storeys and typically with individual heating ventilation and air-conditioning (HVAC) systems;
C. Medium rise, medium density apartments of four-eight storeys with lifts (elevators) and typically with integrated HVAC systems;
D. High rise apartment towers above eight storeys with integrated HVAC.

The main residential building construction elements are summarised in table 1.

Table 1: Construction elements of representative housing types

TYPE	MAIN STRUCTURAL MATERIALS:			WINDOWS DOORS	HVAC*
	FLOORS	EXT. WALLS	ROOFING		
A	Concrete slab on ground; raised timber ground or upper floors	Brick or concrete block structure or cladding; Timber or steel frame with brick, lightweight sheet or foam board clad with paint or rendered finish	Timber or steel truss/framing; Cladding – clay or concrete tiles; metal tiles or sheeting; less common fibre cement sheeting or Slate (rare)	Windows – aluminium, steel, timber or plastic frame with glass. Doors – timber, steel with timber or steel frames	Normally natural ventilation; Ceiling fans; Individual unit air conditioning units or systems
B	Concrete slab, suspended slab; timber upper floors	Brick or concrete block structure; Timber or steel frame with brick, lightweight sheet or foam board clad with paint or rendered finish	Timber or steel frames; Tiles-clay or concrete; Metal sheeting	Windows – aluminium, steel, timber or plastic frame with glass. Doors – timber, steel with timber or steel frames	Combination of natural ventilation, fans; Individual unit air conditioning units or full systems
C	Steel reinforced concrete slab, suspended slab system flooring	Brick or concrete block; poured steel reinforced concrete with paint or rendered finish	Steel frames and pitched or flat sheet roof in metal or concrete	Windows – steel, aluminium or plastic frame with glass, window walls. Doors – timber, steel	Natural and/or mechanical ventilation with individual unit or integrated air conditioning units
D	Steel reinforced concrete slab, suspended slab system flooring	poured steel reinforced concrete; Brick or concrete block with paint or rendered finish	flat sheet roof in metal or concrete with embellishment	Extensive use of integrated window walls as above Doors - as above	mechanical ventilation with integrated HVAC systems

* HVAC = Heating, ventilation, and air conditioning systems

Common residential building elements include:

Plumbing - PVC plastic, copper piping; steel and plastic guttering and downpipes. Internal fixtures and fittings in plastic, ceramic and vitreous enamel materials. Fire systems - steel and copper piping.

Electrical - PVC coated copper cabling, steel and plastic installation fittings.

Insulation - fibreglass, wool, paper, rockwool, aluminium foil.

5.2 Case study research

Representative cases of this urban residential typology in the City of Gold Coast will be selected for MFA assessment. If it can be shown that there is a significant variation in oil supply vulnerability and therefore sustainable residential forms, then the intervening and moderating variables in figure 4 will become important in achieving viable outcomes for urban development in an oil constrained future.

These studies will inform consideration of which urban forms should be promoted in strategic spatial planning, and will reinforce outcomes of other studies–e.g. urban transport and embodied energy–to manage global city growth.

6 Conclusions

The literature provides strong qualitative evidence that peaking of global oil supply will end the era of 'cheap oil' and cause supply constraints and dramatic price inflation. It will affect the current business-as-usual approach to urban growth management in all developed nations, which are inextricably dependent upon the petroleum economy.

Oil depletion has the potential to cause a catastrophic breakdown of urban and particularly suburban economic livelihoods and social lifestyles. One area well researched quantitatively is the impact of oil vulnerability on transport. Existing suburbs are likely to survive the interim post peak oil transition period–albeit subject to much higher private transport and lifestyle costs–only if those communities make some degree of transition to a more resilient state.

When oil depletion gradually becomes a significant constraint on urban development, the full implications of society's reliance on the oil economy will become evident and a fundamental transformation to sustainable city forms powered by renewable energy will evolve. It could be a back-to-the-future move.

The literature research has failed to reveal conclusive information how future oil constraints (including petrochemical dependency) and related factors of oil supply adaptation may adversely affect provision of urban infrastructure and building development, thus affecting feasibility of some residential forms.

The research points to a tentative hypothesis that:

> *Relationships linking oil related inputs to urban development suggest some current forms of residential development in the Australian context may become unsustainable in a future with globally 'constrained' oil supply.*

This hypothesis has led to an investigation of how to assess the likely impact of oil depletion on the vulnerability of future urban residential development and hence its impact on urban metabolism, consistent with the key relationships between oil inputs and urban development form shown in figure 4.

A suitable tool for such assessment is partial material flow analysis. Case study research will examine the flows of oil and gas related substance and material resources and energy from source through land development and building construction for a representative urban residential typology of a selected Australian city. These studies will inform consideration of which urban forms should be promoted in strategic spatial planning to manage future city growth.

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