

# **Knowledge is Power: A Quantitative Assessment Method for the Environmental Impact of Different Urban Development Patterns**

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## ***Abstract:***

*In New Zealand, urban growth policies mainly recommend an increase in the footprint density of housing in urban areas. This will necessitate a lifestyle change from the users, as the accepted goal is still the detached house and garden for the average New Zealander. However, at present there appears to be no method that allows a quantitative comparison as to whether one footprint pattern has a lower environmental impact than another. This paper presents some results from a quantitative study carried out to calculate the potential sustainability of five residential blocks of Auckland. The original study, on which this paper is based, looked at a range of factors of an urban environmental sustainability equation: domestic energy; transport; food; waste; carbon sequestration and water, used aerial photographs and Geographic Information System (GIS) and developed comprehensive mathematical methods based on ecological footprint assessment techniques. This paper focuses on only two key aspects: domestic and transportation energy use and on-site energy generation potential as an illustration of the methods involved in the wider study. The results from these parameters were added together to determine the most sustainable residential block. The outcomes suggested that the classic New Zealand residential low density suburb (18 households/ hectare) block at a moderate distance from the Central Business District of Auckland may have the greatest potential to be sustainable, although this may also require a lifestyle change for the inhabitants.*

## **Introduction:**

In the process of accommodating future growth, Auckland is transforming very rapidly. As part of this rapid change, it is important to be able to determine objectively whether a given neighbourhood or proposed pattern of development has the potential to be more or less sustainable than another. The controversial debate on socio-economic-environmental sustainability tends to label any low-density developments as unsustainable sprawl whereas compact developments are often presented as 'today's visionary solution' (Guy et al, 1999, p.268) for sustainable future urban form. William et. al. (2000) concluded that 'The search for the ultimate sustainable urban form perhaps now needs to be reoriented to the search of a number of sustainable urban forms which respond to a variety of existing settlement pattern and contexts.' This paper presents a sample of the results of a quantitative study carried out on five residential blocks in Auckland. Dwellings and their servicing infrastructure form an integral part of the future built environment, and their pattern of development can affect national energy demand and resource consumption over a long period of time. Therefore, residential blocks have been considered for this study. This paper identifies the most potentially sustainable residential block from a 'bottom up' approach, by extrapolating from the household scale, but it considers only two aspects of sustainability, domestic energy use and transportation demand for travel to work. In the original study on which this paper is based the factors considered were domestic energy, transport, food, waste, carbon sequestration and water. These were chosen as key global-scale aspects of environmental sustainability that need to be considered for any urban development. Different mathematical methodologies were developed for each of these factors, but within the scope of this paper it is not possible to do more than give a simplified outline of the complex methodologies used for calculating

two of the factors. There is a much wider range of issues that could be considered, but if those listed above cannot be managed in a sustainable manner there is little long-term future in considering others.

**Site Selection:**

The five sites used in this study were selected to give a spread of residential forms and layouts based on the following factors:

- the distance from the city centre;
- zoning pattern according to Operative Auckland City District Plan 1999;
- site configuration and form;
- proximity to the main transport corridors and shopping facilities;
- maximum length of residential blocks between two roads below 300 metres;
- total number of households between 50 to 125 and
- density pattern of area.

These five residential blocks are located as follows, in order of increasing distance from Auckland Central Business District (CBD).

<i>Area unit</i>	<i>Density of area unit</i>	<i>Descriptor</i>
Freeman’s Bay	36.7 persons/ha	Wellington Street
Ponsonby	43.2 persons/ha	Richmond Road
Sandringham	41.2 persons/ha	Sandringham Road
Roberton	27.4 persons/ha	Methuen Road
New Lynn	17.3 persons/ha	New Lynn

Wellington Street with residential zoning 7a contains two to three storey row housing, trapezoidal in form and has a greater density than the average for the area unit. Richmond Road with heritage residential zoning 1 has detached houses from the Edwardian and Victorian era and is rectangular-linear in form. These two residential blocks lie at proximity to Ponsonby Road and are located very close to the CBD. On the other hand, New Lynn, situated at the boundary of Waitakere City and Auckland City is irregular in form, low density and is located close to New Lynn Shopping Mall, Great North Road and Rata Street. Methuen Road with residential zoning 6a and 5 is parallelogram in form, located near the shopping areas of Mount Albert, close to New North Road and Blockhouse Bay Road and have large single storey, two and three storey detached family houses with generous open spaces. Sandringham Road with residential zoning 6a, 6b and 7a is more rectangular in form, situated near the St. Lukes Shopping Mall, close to Sandringham Road and Balmoral Road and has a mixture of two storey row housing units, single and two storey detached, semi-detached and attached houses. These five residential blocks are located at approximately between 10 km to 1 km distance from the CBD of Auckland.

**Methodology for Calculation:**

The existing land use patterns of the residential blocks were calculated using both the GIS based ‘CITYgreen’ software as well as a manual graphical method using an appropriate grid at a scale of 1:1000. The results of both methods were compared which established the accuracy of the methodology. The existing land use patterns contain mainly two categories:

i) non-productive land:

- roof areas of buildings
- road areas including half site perimeter road width
- paved/non paved pathways
- existing vegetation cover

ii) productive land (i.e. available for growing additional biomass):

- remaining open spaces

additional measurements:

- total available solar efficient roof areas of buildings (oriented  $45^\circ$  on either side of North) (Breuer et al, 1994)
- total site area



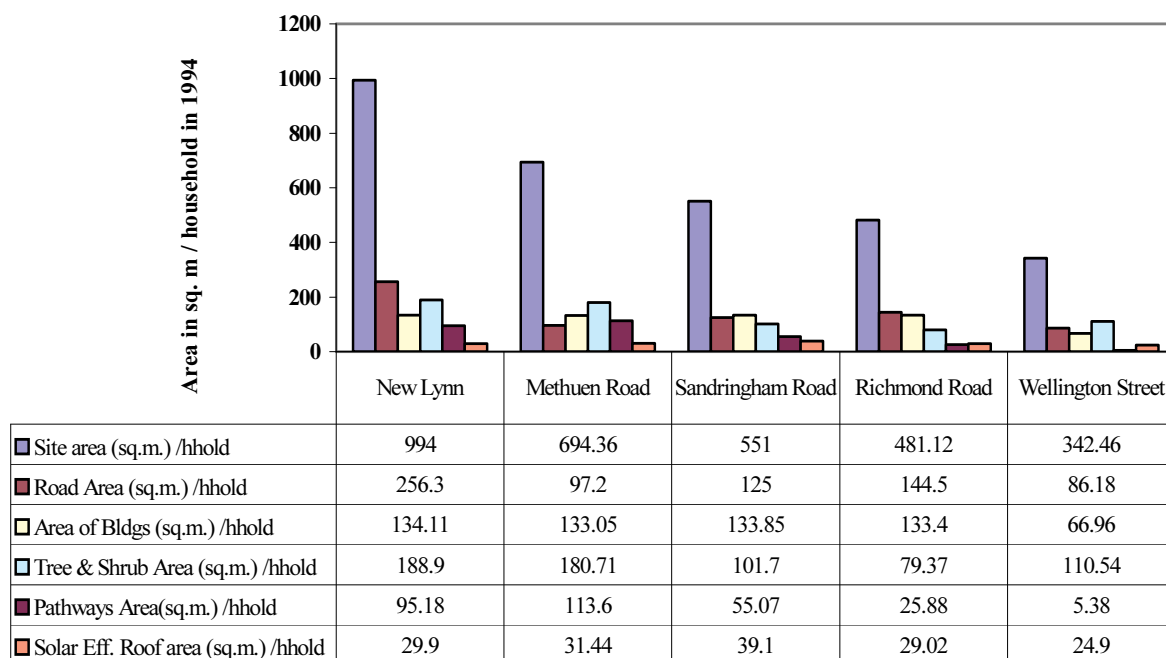
***Fig 1 Sandringham Road Land use Pattern Map***

Data for the calculations were collected from various sources, mainly from aerial photographs, rapid visual survey and national and international databases such as census, publications and reports. The basis of the calculation was from aerial photographs taken in 1994 and therefore, all the data for calculations were aligned with the same base year to achieve appropriate results. The sustainability ranking of the blocks is therefore a ‘snapshot’ taken at a particular time, but it could be updated using more recent data.

This paper focuses on the methodology to determine sustainability of these residential blocks in terms of only the domestic energy and transportation sectors. Table 1 shows how the land uses differ between the five blocks.

**Table 1: Existing Land Use Pattern, Density per hectare & Total Solar Efficient Roof Area**

Parameter	New Lynn	Methuen Road	Sandringham Road	Richmond Road	Wellington Street
<b>Total Site Area (ha) (100%)</b>	5.27	8.25	6.72	3.13	3.56
<b>Area of Road with Half width, grass and pedestrian path (ha)</b>	1.4 (26.6%)	1.16 (14.1%)	1.52 (22.6%)	0.94 (30.0%)	0.89 (25.3%)
<b>Total Trees &amp; Shrub area (ha )</b>	1.1 (20.9%)	2.15 (26.0%)	1.21 (18.0%)	0.518 (16.7%)	1.15 (32.3%)
<b>Total Paved pathways excluding road area (ha)</b>	0.50 (9.5%)	1.35 (16.4%)	0.67 (10.0%)	0.17 (5.4%)	0.056 (1.57%)
<b>Buildings roof area (ha )</b>	0.71 (13.5%)	1.6 (19.4%)	1.62 (24.1%)	0.87 (27.8%)	0.62 (17.41%)
<b>Productive Land Area (ha )</b>	1.56 (29.5%)	1.99 (24.1%)	1.69 (25.3%)	0.64 (20.1%)	0.83 (23.4%)
<b>Total solar efficient Roof area (ha) (as % Total Roof Area)</b>	0.21 (29.6%)	0.37 (23.1%)	0.48 (29.6%)	0.19 (21.8%)	0.29 (46.8%)
<b>Total no. of households</b>	53	119	122	65	104
<b>Total no. of people</b>	156	348	359	190	305
<b>Density assuming No. of persons / ha</b>	30	42	53	61	86
<b>Density assuming No. of households / ha</b>	10	14	18	21	29



**Fig 2 Land Use Pattern per household in 1994**

## Domestic Energy Use

Domestic energy use for each residential block was calculated by multiplying national average per capita domestic energy use for a particular energy end-use sector calculated from the Energy Efficiency Conservation Authority Energy End-use Database (EECA, 2000, Fig 2.4A, p.31 and p.117) by the respective potential population of the residential block.

Domestic energy generation potential of residential blocks was calculated using two methods. To start with, the Deficit Energy Method calculated the per capita deficit energy requirement for each residential block from the estimation of total energy use. The deficit energy use is the energy that could not be provided from on-site renewable sources. The energy use was grouped into two sections, water heating and the rest (space heating, cooking, refrigeration, lighting and others) because energy needed for water heating can be produced using a solar water heater but energy for the rest of the activities will need to be electricity generated from photovoltaic modules.

**Table 2 Deficit Energy Method - Comparison of Annual Energy Use, Available & Deficit Energy Requirements in 1994**

Parameters	New Lynn	Methuen Road	Sandringham Road	Richmond Road	Wellington Street
Total energy use in residential block (GJ /year)	2277	5080	5241	2774	4321
Total number of households	53	119	122	65	104
Total available solar efficient roof area (m <sup>2</sup> )	1580	3742	4771	1887	2590
Total required area of solar water heater(m <sup>2</sup> )	212	448	488	260	404
Total available Energy from Solar water heater on site (GJ/year)	420	943	966	515	824
Total available solar efficient roof area for PV modules (m <sup>2</sup> )	1368	3294	4283	1627	2186
Total available energy from PV modules on site (GJ/year)	999	2405	3127	1188	1596
Total potential energy from solar water heater and PV modules on site (GJ/year)	1419	3348	4093	1703	2420
Total deficit energy requirement (GJ/year)	858	1732	1148	1071	1901
Total deficit energy requirement per household except transport (GJ/year/household)	16.2	14.5	9.4	16.5	18.3

It was assumed (EECA and CAE, 1996, p.24; CAE, 1996, Vol.1, p.186) that a 4 m<sup>2</sup> per household solar water heater area would be sufficient on average for all sizes of household and this would need to be placed on part of the solar efficient roof area. 50 m<sup>2</sup> of photovoltaic (PV) modules can generate 100 MJ /day assuming 10% efficiency for Auckland (Redshaw and Dawber, 1996, pp.57-58) and PV modules could be placed on the remaining available solar efficient roof area after installation of 4m<sup>2</sup> of solar water heater collectors on the roofs of buildings.

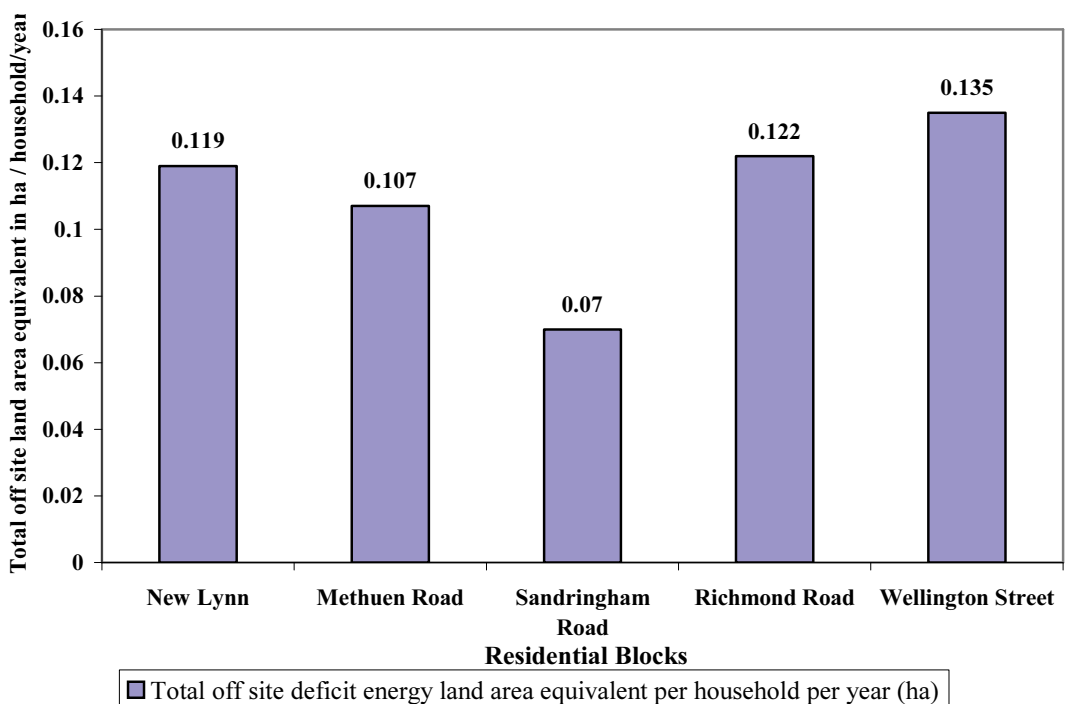
The Land Area Method is based on Ecological Footprint techniques and converts the deficit energy consumption to land areas to calculate the maximum offsite land area needed to meet the overall energy demand of the residential block to grow the energy that they need. The total energy requirements of each residential block were added and converted into the corresponding land area in hectares, which would be needed to generate the required amount of energy. Generally the land-to-energy ratio for New Zealand is assumed to be 120 to 150 gigajoules (GJ) per hectare per annum (Wackernagel and Rees, 1996, p.72). Assuming the average land-for-energy ratio is 135 GJ per hectare per year, the total amounts of available productive land on-site and off-site for each housing area as well as per household were calculated.

**Table 3: Land Area Method - Comparison of Land Area Equivalents of Energy Use, Deficit and Available Energy in Residential Blocks**

<b>Land Area required in the housing</b>	<b>New Lynn</b>	<b>Methuen Road</b>	<b>Sandringham Road</b>	<b>Richmond Road</b>	<b>Wellington Street</b>
<b>Total energy requirement (except food &amp; transport) (GJ)</b>	2277	5080	5241	2774	4321
<b>Total land area needed to generate required energy (ha)</b>	16.9	37.6	38.8	20.5	32.0
<b>Total land area (ha) per household per year</b>	0.32	0.32	0.32	0.32	0.31
<b>Total available energy on site (GJ)</b>	1419	3348	4093	1703	2420
<b>On Site Land area equivalent energy generation (ha)</b>	10.5	24.8	33.5	12.6	17.9
<b>Total on site land area available for energy generation per household per year (ha)</b>	0.198	0.208	0.281	0.194	0.172
<b>Total deficit energy (GJ)</b>	858	1732	1148	1071	1901
<b>Off Site Land area equivalent of deficit energy required</b>	6.35	12.83	8.5	7.9	14.08
<b>Total off site deficit energy land area equivalent per household per year (ha)</b>	0.119	0.107	0.07	0.122	0.135
<b>Ratio of deficit off site land area to available on site land area per household per year</b>	0.6	0.5	0.25	0.63	0.79

The ratio of deficit off- site land area to available on- site land area per household per year varies from 0 to  $\infty$ . When this ratio is equal to zero, the maximum degree of sustainability is achieved. At a value equal to 1, the degree of sustainability is 50% and it decreases with the increasing value of the ratio. At a value equal to  $\infty$ , the degree of sustainability is the least.

Figure 3 indicates that considering only domestic energy consumption and generation (excluding transportation) Sandringham Road with household density of 18 households per hectare has the highest potential sustainability and Wellington Street with household density of 29 households per hectare has the least potential sustainability.



**Fig 3 Comparison of Land Area Equivalents (ha) of Deficit Domestic Energy per Household per year (1994) excluding Transport**

### Transport Energy Use:

The Auckland Regional Land Transport Strategy is guided by the Auckland Regional Growth Strategy, which puts emphasis on a more compact urban form. Urban form is to a large extent a function of transport networks and hence transportation energy use is very important in developing sustainable measurement methodology at a local level. The annual energy use and CO<sub>2</sub> emissions in transport were calculated based on known work trip length, using Area Unit based data from Statistics New Zealand for the length of the journey to work applicable to each of the residential blocks (Whitehead, 2001). The lengths of journey to work vary with the location of Area Units and thus take into account locational aspects of residential blocks situated in different Area Units in addition to their residential density. All the transport energy uses for travel to work in kWh was converted into GJ and all GJ into corresponding land area equivalents in hectares using the same technique as for the domestic energy use calculations (using an average value of 135 GJ per hectare per annum). The main assumption was

that the private transport included only cars and public transport included only buses. This is because of the total energy consumed for domestic travel in 1998, 90% was attributed to cars (EECA, 2000, p.v). A travel survey of New Zealand by the Land Transport Safety Authority, 2000 (LTSA, 2000) indicates that most household vehicles, vans and utes in New Zealand were of engine size 1601cc to 2000cc. The average of 1800 cc was taken for this calculation. Average CO<sub>2</sub> emissions by a 1.8 litre petrol car at 20% occupancy are calculated to be 0.225 kg per passenger km. and also average energy use is calculated to be 0.83 Kwh per passenger km (data for CO<sub>2</sub> emissions and energy use from Vale and Vale, 1998, Table 6, p.4). Similarly the energy use and CO<sub>2</sub> emissions for a bus at 20% occupancy are also calculated (ibid, 1998, Table 4, p.3). The total transport energy required by a residential block is considered to be equal to the total deficit energy in transport as nothing could be generated on site. The use of cars could be reduced only if there was a behaviour change in the people to use more public transport and use pedestrian facilities. The travel pattern and trends as estimated by the Auckland Regional Council in the Auckland Regional Land Transport Strategy (ARLTS) 1999 showed that 24% of all household journeys are to and from work with an additional 5% work related journeys thus making 29% of all household journeys work related (ARLTS, 1999, p.24).

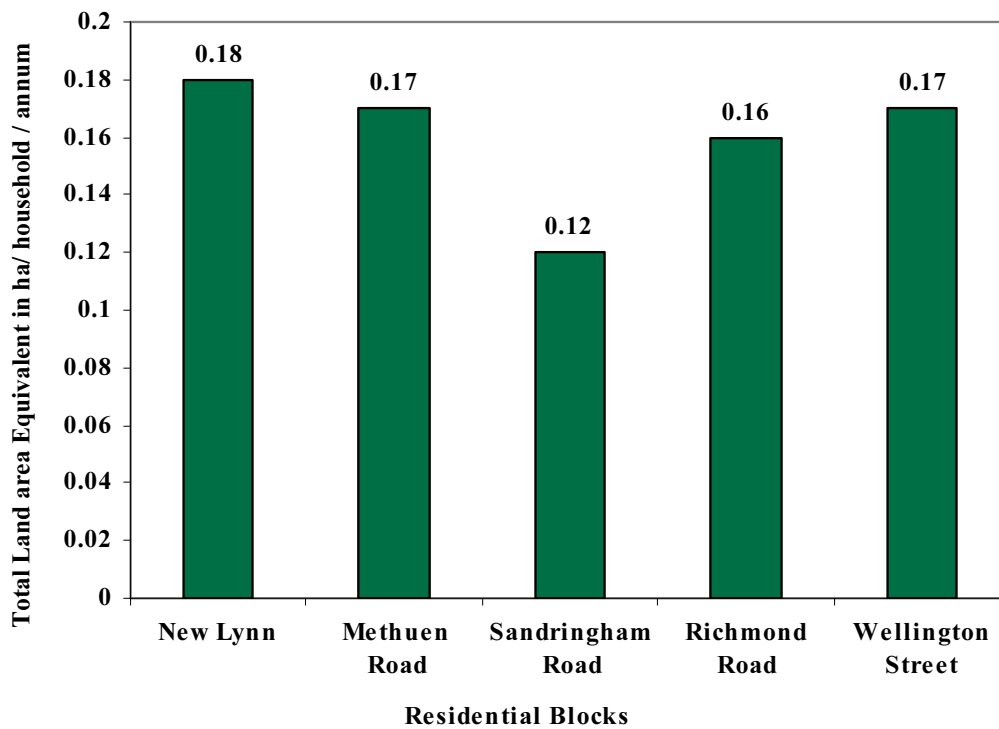
**Table 4 Calculations for the Total Transport Energy Use and CO<sub>2</sub> Emissions by the Cars and Buses**

<b>Residential Blocks</b>	<b>Energy use by cars per annum in 1994 (GJ)</b>	<b>CO2 emissions by cars per annum 1994 (tons)</b>	<b>Energy use by buses per annum 1994 (GJ)</b>	<b>CO2 emissions by buses per annum 1994 (tons)</b>	<b>Total energy use per annum in 1994 (GJ)</b>	<b>Total CO2 emissions per annum 1994 (tons)</b>	<b>Total Land area equivalent of work trips energy use per household (ha)</b>
<b>New Lynn</b>	417	31	12	1	429	32	0.060
<b>Methuen Road</b>	936	71	27	2	963	73	0.060
<b>Sandringham Road</b>	810	61	24	2	834	63	0.051
<b>Richmond Road</b>	308	23	9	1	317	24	0.036
<b>Wellington Street</b>	451	34	13	1	464	35	0.033

It has been also assumed that the mean work journey trip lengths for each Area Unit apply per household. Public transport includes only buses and excludes ferries and trains, as the applicability of these modes for the residential blocks is not known. Due to the non availability of data, non work trip were not included in the calculation. Limited research in New Zealand suggests that people moving into medium density developments do not demonstrate changes in transport behaviour (Dixon and Dupuis, 2003), meaning that the average modal split for Auckland was assumed to apply.

**The Sustainable Residential Block:**

The sustainability performance of the residential blocks was thus measured in terms of domestic energy use and work journey transport energy use and results were added together to determine the most sustainable residential block in terms of these two factors.



*Fig 4 Comparison of Deficit Land Area Equivalents (ha) per household per year based on Domestic Energy and Transport Energy for work travel*

### **Conclusions:**

The sustainability performance of five residential blocks in Auckland was measured in terms of domestic energy use and work journey transport energy use. The results indicate that compact urban form may limit the potential sustainability of residential blocks. As measured in this paper the most sustainable urban form was a low-density (18 households/ hectare) residential block at a moderate distance from the CBD. This is in spite of the fact that compact development is usually cited as reducing the need for transport. The sustainability factors illustrated in this paper are limited to two in order to demonstrate the approach. Even considering only the two factors, further research could be carried out to demonstrate the impact of behavioural changes, such as energy conservation in the home, wider take-up of public transport, or the adoption of more efficient private vehicles. The inclusion of a wider range of factors than those used in the original study is possible, as the approach is flexible, and the inclusion of other factors might change the rankings of the residential blocks. In future, the mathematical methodology developed in this research can be applied towards formulation of urban density standards in relation to energy consumption and development patterns of urban areas using a larger sample size. It opens up the possibility to develop a model estimating the comparative degree of environmental sustainability of various urban forms at local, regional and national levels.

### **Acknowledgements**

The authors would like to acknowledge the support of the FRST funded “Learning Sustainability” programme involving Landcare Research in collaboration with Opus International Consultants Ltd. and the University of Auckland. The authors also sincerely thank the University of Auckland for funding the original research. They would also like to thank the Auckland City Council for the aerial photographs. For assistance in sourcing relevant materials thanks to staff members of the General

Library, Massey University, Palmerston North and the Architecture Library of the University of Auckland.

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