Chapter 34
An Integrated Simulation and Visualisation Platform for the Design of Sustainable Urban Developments in a Peri-Urban Context

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Abstract Designing sustainable urban development is a multi-dimensional and multi-disciplinary challenge that can benefit from next-generation modelling tools to achieve high performance outcomes and integrated assessments. This chapter presents and demonstrates the use of 'MUtopia', an information modelling platform for assessing alternative urban development scenarios. The use of the platform is illustrated through the application to a peri-urban development in the city of Melbourne, Australia. The modelling platform allows simulation of various transition and future scenarios at the precinct level. The platform is capable of extracting data to assist in developing and assessing the performance of different components (land use, individual buildings and infrastructure related to energy and water supply and use, waste management and transport systems) by taking advantage of the platform's unique scalability. The selected case study is a 31.5 ha Parcel of land, a typical peri-urban development in Melbourne's fringe located in West Cranbourne. A key aspect of the development is the design of a sustainable precinct that is affordable, provides a greater level of amenity and incorporates biolink corridors and natural open spaces critical to the preservation of native biodiversity. As a low rise suburban development this project presents a unique opportunity for the application of the MUtopia platform and to demonstrate how the tool can lead to optimum design parameters for achieving sustainable development. This chapter also describes how MUtopia can be used to optimise the selection and design of sustainable and resilient energy, water and waste infrastructure and its integration with existing infrastructure.

Keywords Urban development • Performance outcomes • Infrastructure • Biodiversity • Sustainable development • Modelling platform

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34.1 Background

Fast growth is being witnessed in the world's urban and peri-urban regions due to unprecedented rural migration coupled with natural population growth. In 2008, the number of people in cities surpassed 50 % of the total population for the first time in our history and will likely reach up to 70 % by 2050. In the same time-frame global population is expected to reach 9.3 billion with most of the growth taking place in the world's developing regions and mainly in peri-urban areas. This influx and development will dramatically change the makeup of peri-urban landscapes. Converting agricultural land for urban use will require holistic planning and systematic consideration to food, energy and water services, and ensuring sustainability will be of utmost importance.

These changes make peri-urban areas highly dynamic in their makeup and understanding these dynamic changes presents significant challenges. Research has been conducted on specific aspects of peri-urban growth such as water, energy and infrastructure, however, there is a paucity of research efforts placed on using an integrated systems approach such as UrbanSim (Waddell 2002).

It is therefore important for policy makers, urban and peri-urban planners and municipal council managers to understand the current issues and future challenges posed by peri-urban development. Significant modelling capability is required to evaluate the multiple sustainability dimensions associated with these dynamic changes. At the core of this challenge is the ability to integrate various subsystems that form a peri-urban system. This entails the ability to take into account the multiple interactions that exist between the multiple processes involved in the peri-urban system. For instance, among others, the provision of water involves significant use of energy and associated carbon emissions, thus modelling of the water supply systems must be closely linked to the energy use system.

This chapter presents an integrated modelling and visualisation platform called MUtopia (Mendis et al. 2012) that is capable of simulating the most important processes involved in sustainable peri-urban growth – water, energy, transport and waste – and the interrelationships between them. The platform is a tool capable of assessing the key sustainability metrics of new or existing peri-urban developments at multiple scales. In this case study, the platform was used to assess several peri-urban development scenarios in the Melbourne outer suburb of West Cranburne comprising a 31.5 ha parcel of land. The design and development places a major focus on sustainability and high amenity levels. These include a bio-link corridor connecting and preserving biodiversity and providing natural open spaces for recreation which must be provided in conjunction with affordable and low to medium rise housing. It serves as a typical application for MUtopia platform enabling demonstrations of how it can be used as a tool to assess design outcomes and assist in the process of achieving integrated sustainable development.

34.2 An Integrated Platform

The MUtopia platform allows for integrated simulation and visualisation of data on a geospatial level. Key sustainability metrics can be quantified and rated while being displayed in a 3-D model of the precinct itself. This 3-D visualisation allows design professionals to quickly assess the outcomes of introducing alternative strategies to increase the likes of energy or water efficiency, waste management, or even construction and maintenance. By integrating a whole range of aspects within the one platform, MUtopia can serve to evaluate urban planning, as well as provide economic modelling associated with operational costs and benefits of a proposed development (Fig. 34.1).

The MUtopia platform was created by a team of planners, engineers, environmentalists and economists. The key features offered by MUtopia include:

- A virtual 3D environment that mimics the real world based on GIS data.
- Visualisation of inputs (such as energy, transport, water demands) and outputs (such as greenhouse gas emissions) both temporally and spatially.
- Analysis of sustainability outcomes through quantitative modelling.
- Capacity to accommodate a range of different demands across a variety of built environment disciplines.
- While Mutopia is primarily designed for modelling precinct level developments, it can handle modelling across small to larger scale geospatial districts.

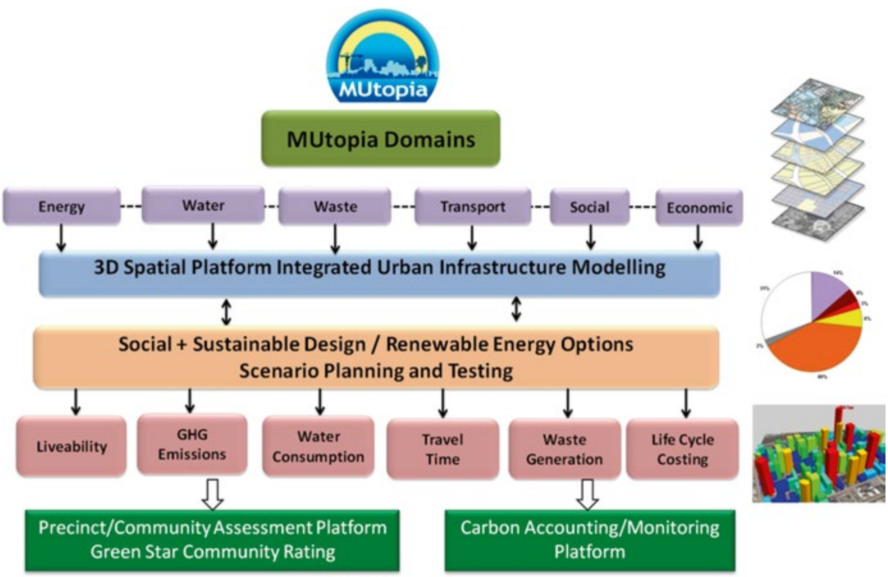

Fig. 34.1 MUtopia domains

MUtopia offers a number of benefits to developers and planners. These include:

- The ability to simulate a range of design scenarios, thus allowing for maximum efficiency in the development and planning process.
- The appearance of being a leader in sustainable development approaches.
- Assistance with meeting legislated greenhouse gas offset targets.
- Improving market position and international profile of users.
- Monitoring of the sustainability performance of a project.
- Proving a commitment to and more easily meeting sustainability benchmarks.
- Allowing for collaborative Community 'consultation' workshops based designs to be modelled for best outcomes.

A number of municipalities in Melbourne have recently added an amendment to their planning schemes to include a clause on Environmentally Sustainable Design. The policy applies to residential, mixed use and non-residential development and requires the developer to submit either a Sustainable Design Statement or Sustainability Management Plan. This submission must respond to design objectives in the following areas:

- Energy efficiency,
- Water resources,
- Indoor environment quality,
- Storm water management,
- Transport,
- Waste management,
- Innovation, and
- Urban ecology (City of Moreland 2014).

The MUtopia platform has the potential to be a very useful tool for quantifying responses to the objectives stated in a Sustainable Design Statement or Management Plan. As more local governments look to include such items in their planning schemes, it will become more important for planners and developers to carry out sustainability assessments.

34.3 Methodology

The process undertaken for this project involved an integrated model that is used to calculate energy and water usage across a range of scenarios. The individual model engines have been developed collaboratively by a number of University of Melbourne researchers. By integrating them within MUtopia, inputs could easily be changed and outputs interconnected within a web application resulting in instant visual and data feedback for the user.

34.3.1 Energy

In calculating future energy usage and resulting greenhouse gas emissions from the West Cranbourne development site, the model in MUtopia was simplified resulting in only modelling residential energy and water usage while assuming that electricity was the only source of energy provided to the site.

Total energy demand for lighting in kW-h/year is estimated by:

$$El = (A \times R) / \eta_l \tag{34.1}$$

where, A = residential floor area, R = basic lighting rate (kLumen.h/m^2.year), η_l = lamp efficiency (lumens/W).

Total energy demand for cooking in kWh/year is given by:

$$Ek = c_k \times p \tag{34.2}$$

where, c_k = energy demand for cooking per person (kWh/person/year), p = the number of residents.

Total energy used for space heating in kW-h/year is calculated by:

$$Eh = a \times b \times c \times d \times f \times m \tag{34.3}$$

And total energy used for space cooling in kW-h/year is calculated by:

$$Ec = a \times (1 - b) \times c \times e \times f \times m \tag{34.4}$$

where heating energy, *Eh*, and cooling energy, *Ec*, are taken as multiples of a range of factors outlined below and gross floor area, m (m^2).

a = ratio of met load to modelled load
b = heating as a fraction of total heating and cooling energy
c = AccuRate thermal performance based on climate zone
d = space heating technology factor
e = space cooling technology factor
f = conditioned floor area as a fraction of gross floor area (GFA).

Appliances and equipment energy consumption in kWh/year are given by:

$$Ea = \sum (Estar \cdot n) \tag{34.5}$$

where, *Estar* = appliance consumption from each household (kWh/household/person), and n = number of dwellings.

Appliance consumption per household (kWh/household/person) is given by:

$$Estar = Estar1 \times (1 - Er)^{(star-1)} \tag{34.6}$$

where, *Estar1* = energy usage assuming 1 star appliances and the given the number of bedrooms (kW-h), *Er* = the energy reduction factor and *star* = star rating of the appliance.

Appliances considered: fridge, dishwasher, washing machine and clothes dryer.

Greenhouse gas emissions in kg (CO_2)/year are given by:

$$GHG = E \times VIC\_GHGI \tag{34.7}$$

where *VIC_GHGI* = Greenhouse intensity of electricity in Victoria and is assumed as 1.35 kg (CO_2)/kWh, E = energy usage in kWh/year.

34.3.2 Water

Urban water supply and waste water systems are highly complex. Accordingly the model needs to account for various interactions between subsystems and be applicable to a precinct development. It also needs to be able to link the associated energy use and GHG emissions to the various stages of the urban water life cycle for analysis.

The water balance model developed by Arora et al. (2013) was utilised in this study which takes into account six stages of the urban water cycle: extraction and transport to treatment plants, treatment, distribution, wastewater collection and transport to treatment plants and treatment of waste water and disposal.

34.4 Case Study

The 31.5-ha Natural Resources Conservation League (NRCL) site is located at 950 Western Port Highway, Cranbourne West. It is the intention of the NRCL to create a commercially viable yet sustainable concept master plan to be delivered alongside a range of development models. The development is to have a range of different housing types, plenty of open space, and '*clean light smart industry*'. Particular attention is applied to the makeup of residential dwellings. A mixture of detached houses, townhouses and apartments is designed to ensure the best possible sustainability outcomes. Dwelling arrangement and design aim to maximise accessibility to walkable active spaces, allow best practice surface water management and pay particular attention to biodiversity outcomes. Energy usage on site is to be minimised including having no connections to gas infrastructure. This concept forms part of the plan for Zero Carbon emissions (RMIT Centre for Design 2012).

The following is a list of guidelines outlining the most prominent building types within the development:

1. **Residential**
   (a) Detached Houses – 200 m^2 blocks, one to two story
   (b) Townhouses – 150 m^2 blocks, three storeys
   (c) Apartments – around four storeys
2. **Retail** – small in size, to include the likes of a local grocery, butcher, bakery, small café and possible mini Independent Grocers of Australia (IGA) supermarket.
3. **Commercial** – mainly small offices with an incubator hub for innovative start-ups proposed.
4. **Community and educational** – community facilities and light industry similar to the Centre for Education and Research in Environmental Strategies (CERES), Melbourne.
5. **Potential NRCL headquarters** – As the anchor tenant and precinct manager, the NRCL's headquarters to be prominent and central.

34.4.1 Inputs to the Model

The algorithms used in MUtopia require the following inputs:

- Number of dwellings.
- GFA/dwelling.
- Dwelling heights.
- Percentage of open space.
- Commercial GFA remained the same for all scenarios.
- Percentage of rainwater and grey water harvested.
- Commercial GFA remained the same in all scenarios (just under 20 % of land area) and thus its only effect on the model was a reduction in overall site area.
- No natural gas infrastructure – only electricity assumed (linked to Zero Carbon).
- 5 star water fittings were assumed in all scenarios.

34.4.2 Scenarios Investigated

In this particular case study, MUtopia is used to assess residential energy and water uses for three different scenarios proposed in the NRCL Pilot Study (RMIT Centre for Design 2012) conducted by the Royal Melbourne Institute of Technology (RMIT): One of low density and few dwellings, one of medium density but a large number of scattered dwellings, and one aggregated high-density scenario with 50 % occupied by open space.

Table 34.1 Summary of design parameters

Feature	Design 1	Design 2	Design 3
Approach	Medium density	Low density	High density
Number of dwellings	800	500	600
% open space	40 %	35 %	50 %
% low density housing	10 %	25 %	10 %
Arrangement of dwellings	Scattered	Scattered	Aggregated

In 2012, the Centre for Design at RMIT was contracted to investigate and inform the development on the Greenfield Cranbourne West site. As part of this process they conducted a design charrette that brought together an array of experts to collaboratively design the development closely in line with the design principals and site vision. The charrette itself consisted of a site visit, and a number of sessions that looked at setting the boundaries, instilling the design principles and designing the actual site under varying scenarios.

Ultimately, the charrette exercise created five different designs, all with different specifications of dwelling density, open space, service integration and a number of other factors. An initial simplified process of comparative appraisal was then conducted rating each design against design principals. The MUtopia platform was used to evaluate the proposed designs from the charrette in greater detail focusing specifically on energy and water usage and rain and greywater harvesting. Out of the NCRL Pilot study, scenarios 1, 2 and 3 were combined to become one option, *Design 1*, consisting of 800 dwellings. This option was subsequently compared to *Design 2* and *Design 3* (scenarios 4 and 5 respectively from the charrette). Table 34.1 summarises the key characteristic values for each design option used for the comparison.

In assessing the water harvesting potential and overall water efficiency of each of the three *Designs*, they were modelled against rain and greywater harvesting rates of 0, 50 and 100 %.

34.5 Results

MUtopia produced a range of different outputs from each scenario, which enabled their assessment against key criteria, namely: water, energy efficiency and greenhouse gas emissions. Water consumption was calculated and compared with on-site potential to determine how much water would need to be imported from water efficiency off-site. In addition, a proportional water usage graph was produced to demonstrate efficiency on a per resident basis.

Of the three designs evaluated with the model, *Design 2* had the least aggregate water consumption while Design 1 has the largest water capture potential which can be ascribed to the largest number of dwelling and associated impervious area (Fig. 34.2).

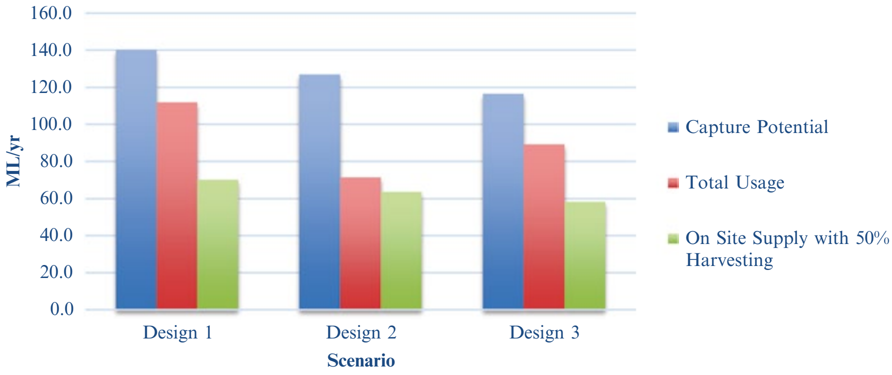

Fig. 34.2 Water capture potential and usage

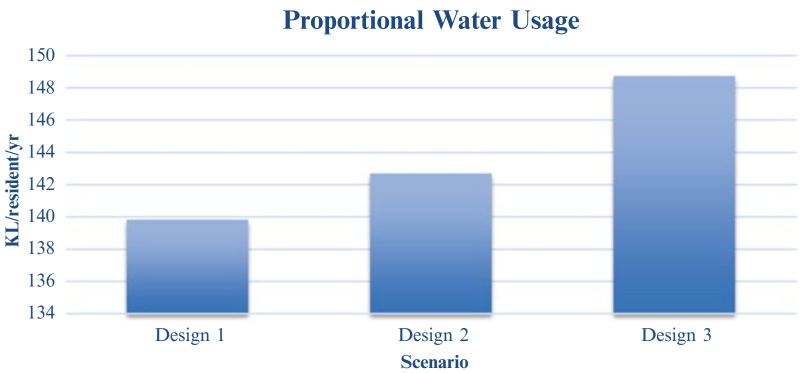

Fig. 34.3 Per capita water usage

When the designs are considered on a per resident basis, *Design 1* with 800 residents is also the most efficient (Fig. 34.3). Conversely, *Design 3* proportionally uses the most water, which is due to the large amount of open green space with high watering requirement.

Design 3 turned out to have the least water harvesting potential as a result of much of the rainfall penetrating into the ground because of large open spaces.

MUtopia proved very useful in providing a numerical as well as a visual tool for explanation to stakeholders. Figure 34.4 provides a visual depiction of the differing land uses on the site showing their capacity for capturing rainwater. By altering the model the user could very quickly understand, visually and quantitatively, the implications of increasing the proportion of impermeable surfaces.

Design 3 proved to be not only the scenario with the most efficient use of energy but also has the least CO_2 emissions per resident (Fig. 34.5). *Design 2*, a low density

Fig. 34.4 Permeable qualities of surfaces

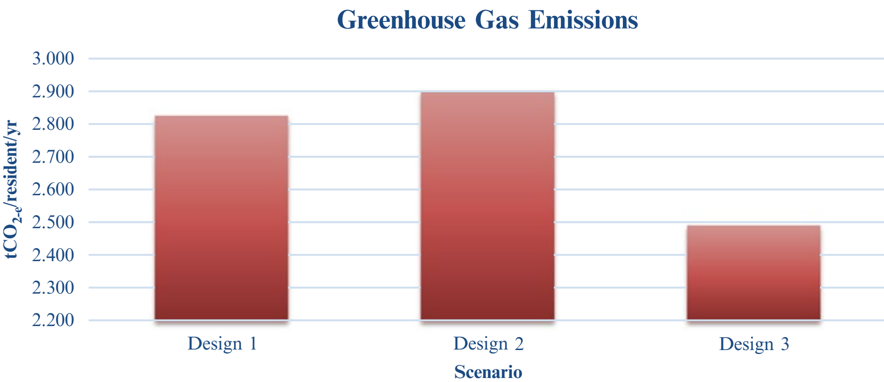

Fig. 34.5 Greenhouse gas emissions per resident

scenario, was the worst performing Design with 2.9 $tCO_{2\text{-}e}$ per resident per year from residential buildings.

The analysis of carbon dioxide emissions by the MUtopia 3-D model demonstrates the relative consumption of various buildings. Figure 34.6 shows a visual representation of total emissions for each building depicted by the relative height of each building. This provides the user with a easy-to-understand visual indicator as to what buildings are responsible for the highest proportion of emissions.

Fig. 34.6 CO_2 emissions by building

Finally, it was found that *Design 3* proved to be the least expensive to operate with utilities totalling just over $100 per year per resident – assuming wholesale energy prices (Table 34.2).

34.6 Discussion

The MUtopia platform provided a practical way of testing three alternative scenarios proposed for the West Cranbourne site development. The main benefits of using MUtopia are the simple format to change the model inputs compared to other tools such as spreadsheets and the immediately viewable data visualisation. The user is able to quickly see what elements of the design that account for most of the varying outputs, and can be readily adjusted to achieve a desired outcome.

The model also provided clear quantitative outputs upon which decisions around choosing a desired design can be made. *Design 3*, based on high-density housing and 50 % open space proved to be the most efficient in all sustainability parameters evaluated except for water consumption. The higher water consumption per resident is due to the large amount of green space which requires significant watering to maintain the green cover.

Table 34.2 MUtopia simulation results summary

Name	Unit	Scenarios		
		Design 1	Design 2	Design 3
Total water consumption	**ML/year**	**111.9**	**71.3**	**89.2**
	kL/resident	**140**	**143**	**149**
Energy electricity	kWh/year	1,289,988	832,730	813,763
Energy water	kWh/year	384,567	241,681	293,364
Energy demand total	**kWh/year**	**1,674,554**	**1,074,411**	**1,107,127**
	kWh/resident	**2093.2**	**2148.8**	**1845.2**
GHG water	tCO_2e/year	519	326	396
GHG energy	tCO_2e/year	1741	1124	1099
GHG emissions total	**tCO_2e/year**	**2261**	**1450**	**1495**
	tCO_2e/resident	**2.826**	**2.901**	**2.491**
Cost energy	$/year	$ 70,756	$ 45,675	$ 44,635
Cost water	$/year	$ 21,093	$ 13,256	$ 16,091
Total cost	**$/year**	**$ 91,849**	**$ 58,931**	**$ 60,726**
	$/resident	**$ 114.81**	**$ 117.86**	**$ 101.21**

In this particular case study, MUtopia allowed visual modelling of building's energy usage by applying colour-coding to buildings based on the energy usage range. The ability to vary density, dwelling numbers and the proportion of water harvesting resulted in performance changes that can assist the user to find a superior design solution depending on their specific objectives.

In particular, the MUtopia platform proved a valuable tool to visualise rainwater capturing potential. This feature can also assist with stormwater management, a growing problem in cities with a high proportion of impermeable surfaces. The platform also has the capability to explore stormwater management, predict flood risk and mitigation options.

While MUtopia was not available at the RMIT's design charrette stage, there is no doubt it would have served to provide useful feedback about each of the scenarios created by the participants at this stage. Scenario testing to assist community consultation, is a task that MUtopia has great potential to assist.

34.7 Conclusions

This chapter describes the MUtopia modelling and visualisation platform and its application to a peri-urban precinct development in outer Melbourne, located in West Cranbourne. The platform fundamental modelling algorithms and visualisation architecture are described together with the physical characteristics of the case study area.

The platform was used to evaluate three Design scenarios distilled from an earlier design charrette for their key sustainability performance variables, with specific reference to water and energy use. The key findings of this analysis showed that:

- The platform proved to be particularly effective in communicating sustainability performance through its quantification and visualisation capability.
- *Design 2* was shown to have the least aggregate water consumption but was the worst performing due to its low housing density.
- *Design 1* proved to be the most efficient per resident water use.
- *Design 3* proportionally used the most water due to the large amount of open green space with a high watering requirement but proved to be the scenario with the most efficient use of energy and least CO_2 emissions per resident.

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