Models for Water sensitive Middle Suburban Infill Development

Tatjana Todorovic[1,6]**, Geoffrey London**[1,6]**, Nigel Bertram**[2,6]**, Oscar Sainsbury**[2,6]**,**
Marguerite A. Renouf[3,6]**, Kerry A. Nice**[4,5,6] **and Steven J. Kenway**[3,6]
[1]School of Design, University of Western Australia, Perth
[2] Faculty of Art, Design & Architecture, Monash University, Melbourne
[3] Advanced Water Management Centre, University of Queensland, Brisbane
[4] School of Earth, Atmosphere and Environment, Monash University, Clayton
[5] Transport, Health, and Urban Design Research Hub, Faculty of Architecture, Building, and Planning, University of Melbourne, Melbourne
[6] Cooperative Research Centre for Water Sensitive Cities, Monash University, VIC, Australia

Abstract: Infill development in Australian cities over the coming decades is expected to have considerable negative influence on the hydrology, resource efficiency, liveability and amenity of our cities. This project aims to develop and apply a performance evaluation framework to understand infill impacts, create design options and processes for improved outcomes through case studies, and identify improved governance options and arrangements.

A 'typologies catalogue' of spatial configurations and architectural models relevant to high amenity medium density infill development has been prepared, with different arrangements and combinations of buildings and open spaces applied on a case study development site in Adelaide, SA. Design scenarios from the catalogue are evaluated against a range of qualitative and quantitative performative criteria, developed in consultation with industry partners, including water and thermal comfort performance assessment. The case study site designs offer practical models and methods for achieving infill development and densification in a manner that improves amenity within the dwelling, across the site and for the surrounding precinct – while maintaining or improving hydrological performance and thermal comfort. During this process, a set of key design principles for water sensitive infill development is defined, with prospects to further inform infill development practice and related policies.

Keywords: Water sensitive city; water sensitive urban design; suburban infill development; typologies catalogue; infill housing typologies.

Water Sensitive Outcomes for Urban Infill Development

Most major cities in Australia expect intensified infill development over the coming decades (Commonwealth of Australia, 2017). Without significant intervention, 'business as usual' development practice is expected to have a considerable negative influence on the hydrology, resource efficiency, liveability and amenity of our cities (Jacobson, 2011; Brunner and Cozens, 2013). The water sensitive city approach aims to support higher density communities while enhancing the environmental performance of Australian cities (Wong and Brown, 2009). It recognises the substantial effect of intensified residential infill development on metropolitan water performance and urban thermal comfort due to its scale and proliferation.

Medium density infill development, utilising efficient design strategies, presents an opportunity to transition towards water sensitive city outcomes (Newton et al., 2012; Newton and Glackin, 2014). Efficient and compact housing design can yield more outdoor space, valuable storm-water infiltration and large tree canopy area. If planned well, the housing can generate higher quality outdoor space facilitating optimised use of resources, eventually reducing overall water and energy demand per dwelling/person (Newton et al., 2012). In addition, climate sensitive urban design can be applied to mitigate increases in urban heat associated with higher urban density (Coutts et al., 2013; Bowler et al., 2010). However, current infill practices, in this paper referred to as 'business-as-usual' (BAU) infill development, demonstrate low site usability and overall performance (Thompson et al., 2017, pp. 177-178). Large building footprints and low-rise developments result in residual and often unusable open spaces, inadequate tree canopy, solar access and cross ventilation, as such expected to show poor water and thermal performances.

A 'typologies catalogue' of spatial configurations and architectural models has been prepared as a component of the Cooperative Research Centre for Water Sensitive Cities (CRCWSC) Integrated Research Project 4 (IRP4), investigating water sensitive outcomes for residential infill developments. This catalogue explores opportunities for improved water sensitivity and liveability for higher density living with different typological models enabling high quality infill development supporting and encouraging water sensitive urban intensification. Its purpose is to provide evidence-based design guidelines, developed through comparative analyses, enabling better informed residential infill practice.

A range of housing typologies, at varying densities and configurations relevant to Australian cities and applicable to different contemporary infill development scenarios, are prepared for an evaluation of their water sensitive performance. ‘Water sensitive’ solutions are developed in an iterative process that are informed by the performance evaluation of water sensitivity, including urban space quality and urban heat. The solutions are then compared to the performance of typologies derived from examples currently found on the market. The catalogue includes design-based testing on several ‘case study’ projects: the Salisbury case study in South Australia, Knutsford in Fremantle, Western Australia, and Norman Creek in Brisbane, Queensland. While modification of developed typologies and their configuration will inevitably be required to fit actual sites and contexts and to realise locally-specific opportunities, the case studies propose and test architectural and urban design strategies that will have impact on water and urban thermal performance, and also on public and private amenity.

In this paper, the infill typology catalogue is described, and the performance evaluation of case typologies developed for the Salisbury case study in Adelaide, SA, are presented.

Typologies Catalogue Outline

Residential infill intensification is particularly evident in middle-ring suburbia, positioned 7 to 25 km away from the city centre, often gravitating around existing local transport and commercial nodes (Newton et al., 2012). With increased infill activity, achieved through lot sub-division, lot amalgamation, and greyfield and brownfield redevelopment, these formerly lower density suburbs with 10-15 dwellings/hectare, are now reaching medium density with 40-60 dwellings/hectare.

Dwelling typologies are planned for typical suburban allotments, distinctive for middle ring suburbs, ranging from 8 to 15m in width and 30 to 50m in depth (Murray et al., 2011). For every typological category, allotment size is adopted based on a selected existing example and used for testing. Each catalogue entry is presented to a consistent layout, with context and floor plans, sections and isometric views, followed by data boxes that include information about occupancy and density rates, water storage capacity, and other data. Diagrams illustrate important spatial information found in the databoxes, for instance, types of outdoor surfaces, the deep root areas, and estimated number of large canopy trees, represented in different colours and symbols. Several examples of catalogue entries are shown in Figure 1 and Figure 2 (see below). Diagrams show spatial organisation and function of both indoor and outdoor spaces, their accessibility and connection, which is used to evaluate qualitative urban and architectural elements relevant for water and thermal performance.

Site Data			
Site Area:	1420 m2	Permeable Hard Surface:	539 m2
Number of Lots:	2	Non Permeable Hard Surface:	0 m2
Number of Dwellings:	6	Vegetated Surface:	532 m2
Density:	42 dwellings per hectare	Deep Root Zones:	8 (430 m2)
Open Space:	1090 m2	Canopy Trees	10+
Site Coverage:	23%	Additional On-Site Water Storage:	Communal water tanks

20

Dwelling Data:			
Bedrooms:	2 and 3 (per dwelling)	Floor Area (deck):	30 m2 (per dwelling)
Occupants:	2 to 5 (per dwelling)	Garden Area:	42 m2 (private) + 46 m2 (communal) (per dwelling)
Cars:	2 (per dwelling)	Roof Surface Area:	55 m2 (per dwelling)
Building Storeys:	2 (3)	% of roof area connected to rainwater storage:	100%
Building Footprint:	55 m2 (per dwelling)	Rainwater Storage Capacity:	5000L (per dwelling)
Floor Area (building):	110 m2 (per dwelling)	Household water appliances: (per dwelling)	12x shower, basin, 6 x wc, kitch sink, laund tub, wm.

21

Figure 1: Examples of catalogue entries: Water sensitive design for Category 1: Dual occupancy

Figure 2: Examples of catalogue entries: Water sensitive design for Category 4: Six pack. (London et al., 2019)

Infill typologies are categorised according to the dwelling type and occupancy, ranging from small scale infill developments on a single or double lot, over medium scale developments on amalgamated lots, to larger, precinct scale developments. The scale and type of development will impact the internal organisation and function, and the type, size and quality of outdoor space. Developments on consolidated sites and precincts provide an opportunity to utilise communal and public outdoor spaces. Three categories of scale of project and related outdoor space are nominated:

i – Small scale infill developments with groups of two to six dwellings and some communal outdoor space

- Category 1: Dual Occupancy (see Figure 1), Duplex
- Category 2: Courtyard, Terrace House, Townhouse

Category 1 and 2 are typically smaller scale infill developments, two to three dwellings on a single allotment, or four to six on two adjoining lots, achieving densities of 30 to 50 dwellings per hectare. Dwellings share boundary walls on one or more sides and are usually two to three stories high. Water performance analysis is performed on a single or two adjoining lots, the quality of private outdoor spaces and the compactness and efficiency of indoor spaces are dominant attributes in determining the effectiveness of water sensitive design strategies. Communal outdoor space in these typologies is minimal, reserved for shared driveway and occasionally for parking areas. The performance of individual lots is potentially complemented with provision of good quality public outdoor space in close proximity, in which case, good connection and access to public outdoor space becomes an important feature.

ii – Medium scale infill developments, from six to twenty units, with significant communal outdoor space

- Category 3: Stacked, Cluster
- Category 4: Six pack (see Figure 1), Lift Core, Walk Up
- Category 5: Apartment Buildings

This category refers to medium scale infill developments in which strata titled dwellings, houses, units or apartments, are stacked and/or clustered, on two or more consolidated lots. Groups of dwellings are typically planned as one development, which presents an opportunity to apply efficient design strategies for more effective use of outdoor spaces. For these categories, communal/shared outdoor space becomes a dominant feature. When compared with the previous category, each individual unit still contains private space, but communal/shared spaces are larger and better proportioned, accommodating multiple uses and design options. A range of communal outdoor spaces is possible, such as grouped parking. Proximity and balanced connection to good quality outdoor public space could, again, add to the performance of the analysed site. Private outdoor space, on the ground or on the roof or balconies, and the functionality of its layout is relevant for water performance, especially in terms of establishing good connection and balanced transition between private, communal and public spaces.

iii – Large scale infill developments, a combination of several infill dwellings types and public outdoor space, resulting in modified streets, parks and plazas

- Category 6: Urban Spaces
- Category 7: Precincts

Categories 6 and 7, Urban Spaces and Precincts, result from larger block or precinct scale developments, most commonly a redevelopment of former industrial and other rezoned areas, on brownfield, greyfield or greenfield sites within or in close proximity to well-established suburban contexts. Under the Urban Spaces category are typical middle-ring suburban streets and laneways. Water sensitive street design seeks appropriate landscaping and vegetation solutions and permeable surface treatments to increase infiltration and mitigate stormwater runoff, as well as to reduce urban heat island effects and encourage walkability. Considered placement and use of residential indoor and outdoor spaces, are factors that can help activate street frontages and further encourage walkability.

Sites available for precinct-scale infill development can be consolidated or disaggregated, which affects the scale and the reach of water sensitive design strategies. Consolidated precincts are more likely to incorporate a combination of several dwelling types and urban spaces, streets and laneways, and a variety of open public spaces, such as parks and squares. Consolidated precincts provide the opportunity to design well connected, accessible and usable outdoor spaces, private, communal and public. Dwelling amenity and function remain relevant to this category, especially in terms of the dwelling orientation and connection to well-designed outdoor spaces.

Design Scenarios

For the purpose of comparative performance analysis and in order to have a better understanding of water sensitive design features and performances, three scenarios are presented and tested for each typological category. (Figure 2)

- Existing suburban development (Typical Existing)
- Business-as-usual infill development (BAU)
- Water sensitive infill development (WS)

An existing suburban scenario shows a typical development found in middle ring suburbs, presuming no changes to pre-infill suburban allotment and design. (Figure 3.a) Most commonly this is a single dwelling, detached, one to two storeys high, situated on a single suburban lot. Such houses are characterized by generous private, both indoor and outdoor, space, capable of achieving desirable solar access and cross ventilation, and mature tree canopy. The Typical Existing scenario for low rise apartment buildings and walk ups, shows constructions that are two to three storeys high, with a large building footprint and remaining outdoor space typically reserved for access and parking.

The business-as-usual infill scenarios are typically developed as one and two level constructions on a single subdivided lot, or as a group of four to eight units on two adjoining lots, achieving higher density than existing suburban developments. (Figure 3.b) Dwellings are usually detached or semidetached one and two storey houses, or low-rise apartment developments, with large building footprints and driveways, leaving little or no outdoor space for permeable surfaces, vegetation and large canopy trees. Lack of quality outdoor space affects a dwelling's amenity and function, with poor solar access and cross ventilation increasing the need for use of air conditioning.

The water sensitive infill scenario offers alternative design strategies to the business-as-usual practice, particularly in terms of compactness and available outdoor spaces on site. (Figure 3.c) Developed designs propose increased height, with houses ranging from 2 to 4 floors, and unit constructions from 3 to 5. With grouped housing projects, stacked or clustered, proposed for consolidated lots rather than on single lots, there is more capacity to plan and incorporate water sensitive design solutions.

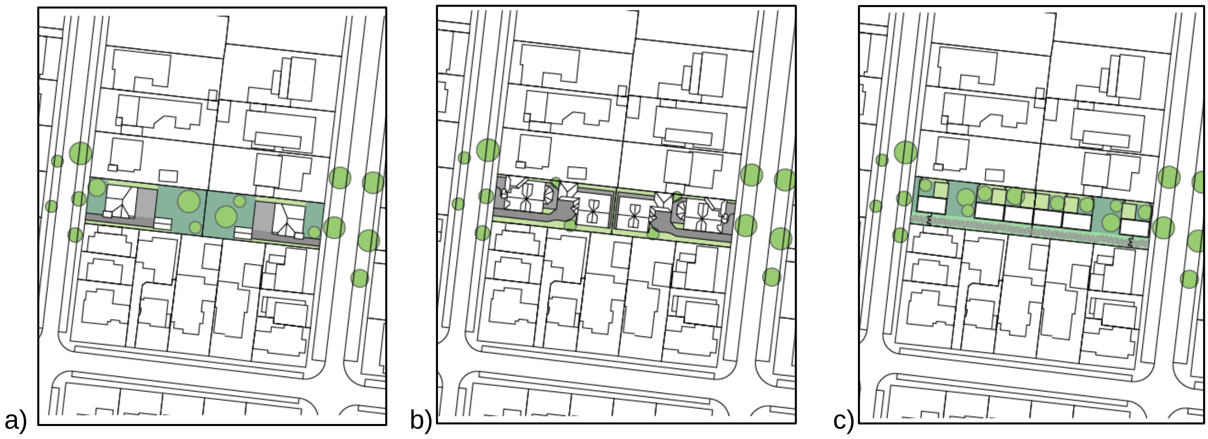


Figure 3: Three scenarios for houses on a typical middle suburban 2-lot site: a) Typical Existing - 2 single-storey detached houses; b) Business-as-usual (BAU) - 4 single-storey detached houses; c) Water sensitive (WS) - 6 two-storey integrated dwellings. (London et al., 2019)

Case study area: Salisbury Centre East

A key objective of the CRCWSC IRP4 research project is to test residential infill typologies that can achieve water sensitive outcomes. This is undertaken by evaluating the performance of different infill typologies at actual case study sites. One of the case study sites selected for the research is the 'Salisbury Centre East' area within Salisbury City in Adelaide, South Australia (Figure 4). It is representative of a small-scale, low to medium density infill development on scattered sites that include individual privately-owned lots, a public housing site, industrial and vacant land. The total case study area is about 90ha, predominantly residential, with some commercial and industrial uses. It is located in close proximity to the Salisbury Town Centre and has good access to public transport, with Salisbury Train Station nearby and metrobus services passing through the precinct.

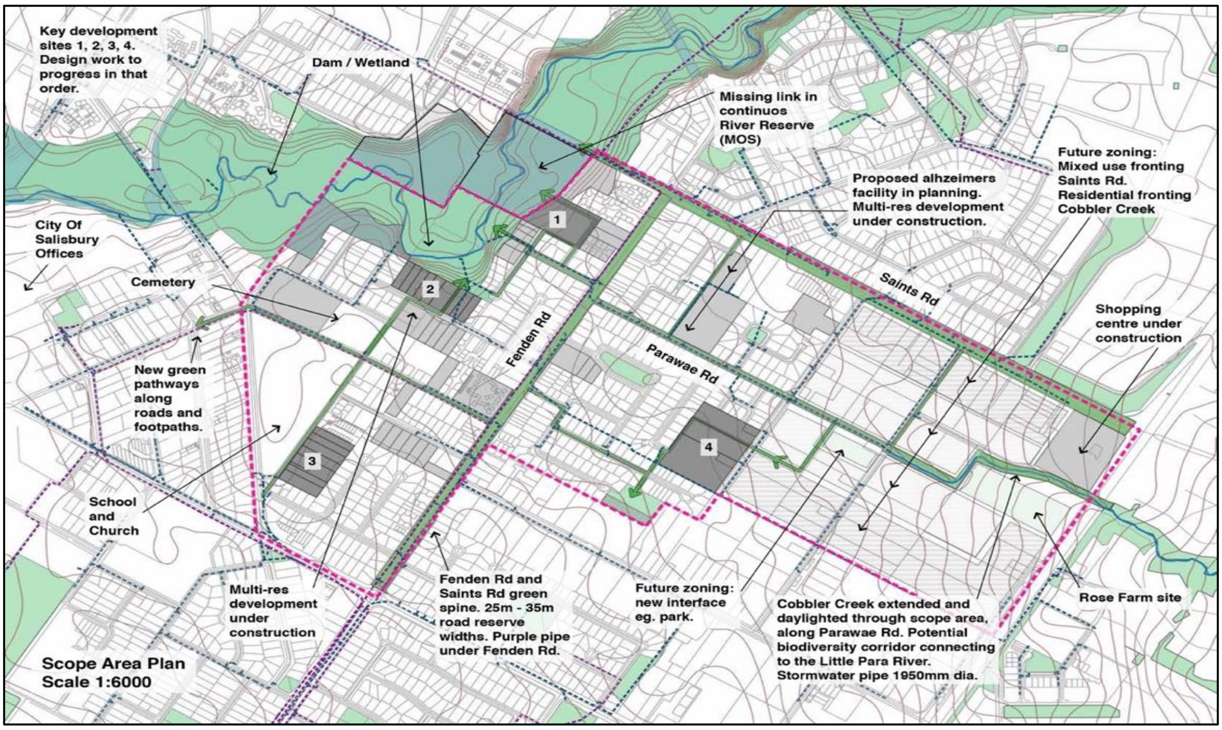


Figure 4: Scope area plan with four nominated sites

The study area is in a “first stage” of urban rejuvenation in accordance with the City of Salisbury Growth Action Plan. Salisbury Centre East together with surrounding suburbs are expected to yield an additional 2500 new dwellings through urban consolidation (Government of South Australia, 2017, p.140). Infill activity has commenced within the study area, and includes single dwelling replacement, dual occupancies, and unit and townhouse developments. However, recent infill development is typified by unit and townhouse developments, surrounded by high amounts of impervious paving and devoid of any green space in common or private areas.

Salisbury Site 1 Performance Analyses

This section is demonstrating implementation of the typologies catalogue for water and urban heat performance analyses on Site 1 of Salisbury case study area (see Figure 4). Site 1 presents an agglomeration of individual lots with a **total site area of 1.384ha**. Figure 5 shows a selection of developed scenarios used for evaluating water and thermal performances. In addition to typical existing and business-as-usual scenarios, a number of water sensitive solutions were developed with different densities proposed (Table 1). The business-as-usual infill option represents a doubling (2-fold) of occupants on the site, the water sensitive options represent higher densification 3-fold, 4-fold and 5-fold the number of occupants.

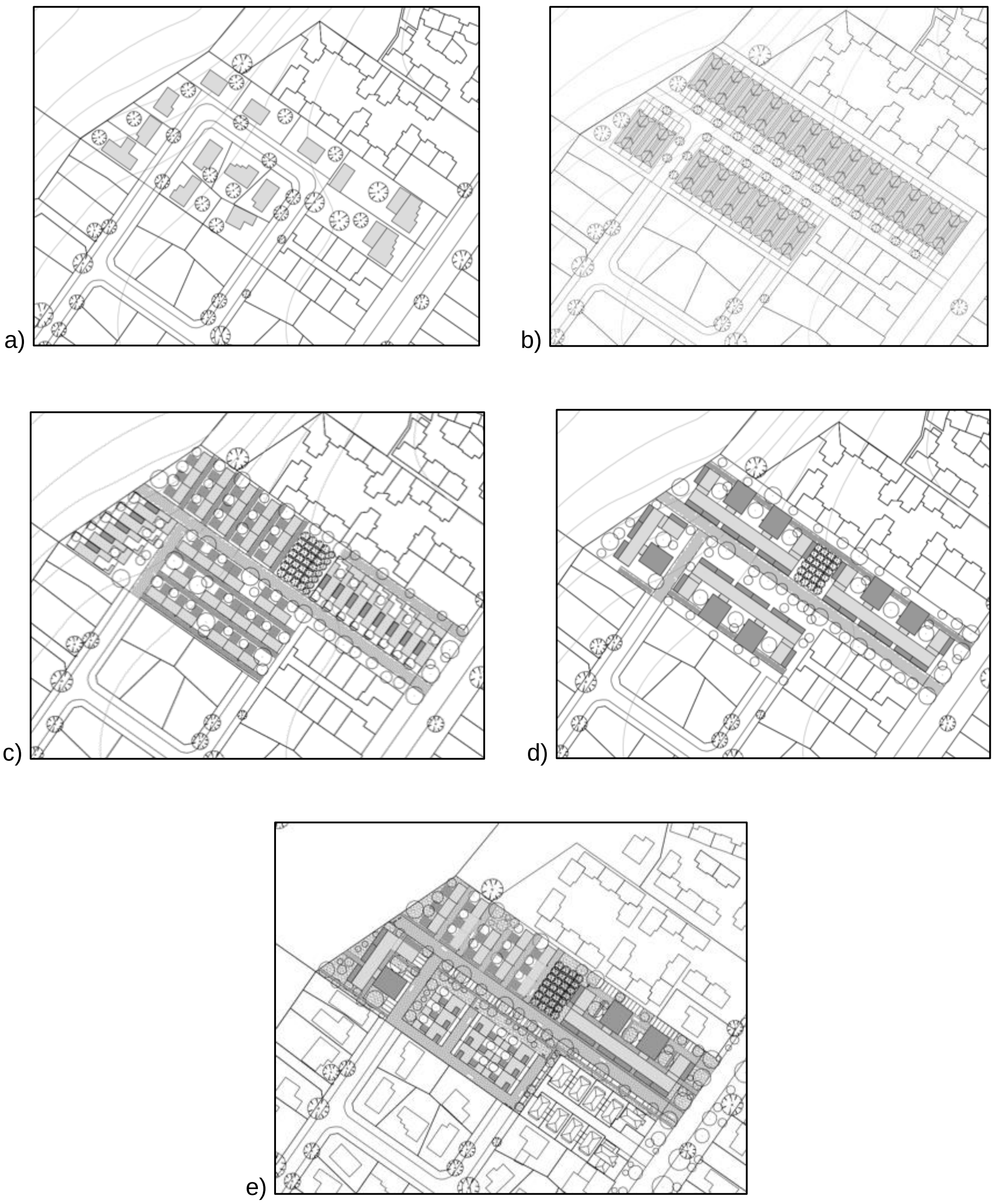


Figure 5: Selection of scenarios developed for Salisbury case study Site 1:
a) Typical Existing; b) Business-as-usual (BAU); c) Water sensitive (WS1) - Townhouses; d) Water sensitive (WS2) - Apartments; and e) Water sensitive (WS3) - Combined. (London et al., 2019)

Table 1: Proposed densities for selected scenarios, Salisbury case study Site 1 (1.384ha)

Scenario	Dwellings	Dwellings/ha	Assumed average occupancy (people/dwelling)	Number of people on the site	People/ha
Typical Existing	13	10	3 (2-4)	39	28
BAU	42	30	3 (2-4)	126	91
WS 1 - Townhouses	46	33	3.3 (2-4)	151	110
WS 2 - Apartments	105	75	2.2 (1-4)	231	168
WS 3 - Combined	69	50	2.5 (1-4)	172	124

Infill designs proposed for the Salisbury case study have been evaluated using the Infill Performance Evaluation Framework (Renouf et al., 2019), which defines the key design parameters and generates performance indicators for a set of desired water sensitive performance criteria. The framework aims to evaluate how urban design and building typologies perform across multiple categories covering architectural and urban space quality, water performance and urban thermal comfort, inform the design process and assist in generating solutions performing well across all criteria. Figure 6 illustrates a potential combination of different performance criteria, including architectural and urban space quality related categories: i – dwelling amenity and function; ii – access to quality outdoor private space; iii – access to quality outdoor communal space; iv – access to quality outdoor public space.

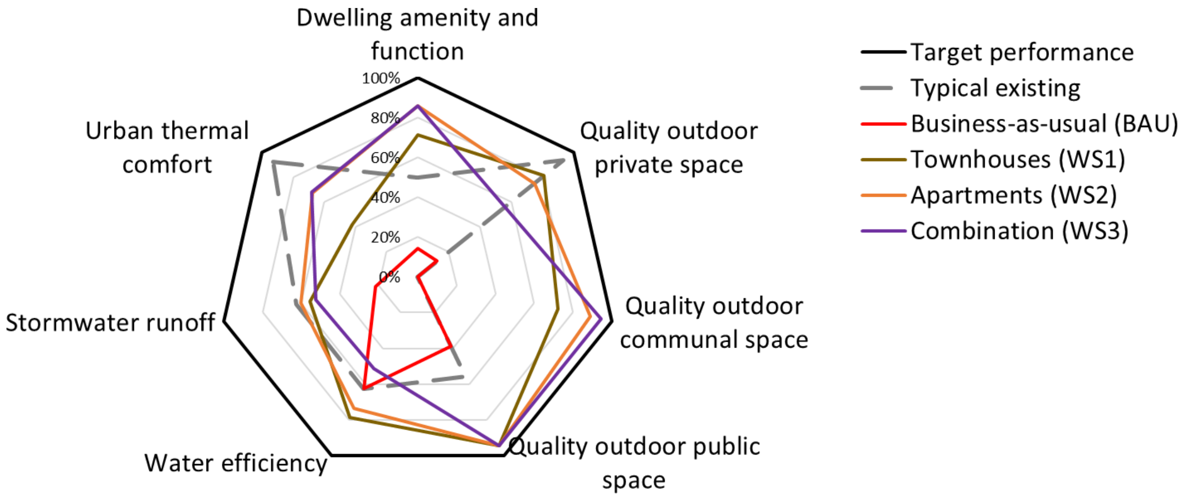


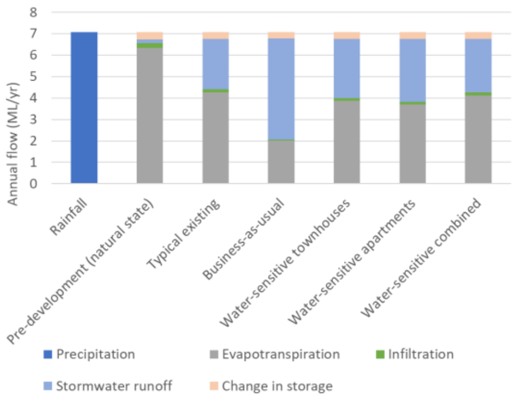
Figure 6: Multi-criteria Infill Performance Evaluation of Salisbury case study Site 1 (Renouf et al., 2019)

Water performance analyses

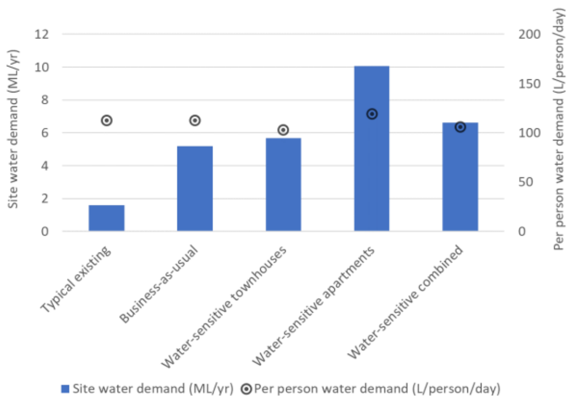
Water performance describes a set of performance objectives related to the protection and functionality of water in the urban landscape, including maintaining water stocks, flows and quality; water use efficiency; and water-related amenity (Renouf et al., 2017). It captures the biophysical qualities of a water sensitive city (Wong and Brown, 2009). In this paper, we focus on indicators of natural hydrological flows (particularly volumes of stormwater runoff), and water use efficiency.

Indicators of hydrological flows (Figure 7) aim to show how much urban development alters natural hydrological flows. Good performance aims to reduce stormwater runoff, by enhancing infiltration and evapotranspiration. Indicators of water use efficiency (Figure 8) aim to show how much water is consumed per person to service the development. Good performance aims to reduce the amount of water drawn from the environment through demand management and through used of fit-for-purpose water harvested from within the urban system.

Water flows for the Site 1 infill typologies were simulated on an annual basis using an *Urban Water Mass Balance* tool) (Lam et al., 2019), from which performance indicators for hydrological flows and water efficiency were generated (Figure 7). From Figure 7 it can be observed that the water sensitive typologies have a similar water performance than the business-as-usual typology, whilst enabling multiple-fold increases in density on the site. In relation to hydrological flow, business-as-usual can be expected to double the amount of runoff compared to the typical existing state, whereas the water sensitive scenarios maintain runoff at similar to existing volumes, while increasing the number of people accommodated, 3-, 4-, and 5-fold, respectively. In relation to water efficiency, all the scenarios were assumed to have the same degree of water use efficiency for appliances and fittings, and outdoor irrigation was not considered. Not surprisingly, total water demand increases with increasing number of people on the site. The per person water demand is influenced by occupancy, and therefore we see higher demand per person for typologies with lower design occupancy, as in the case of the apartment scenario.



a)



b)

Figure 7: Water performance for the Salisbury Site 1 scenarios: a) Hydrological flows (evapotranspiration, infiltration and stormwater runoff); b) Site water demand and per-person water efficiency (Renouf, M, and Kenway, S., 2019)

Heat modelling

Five scenarios with varying canopy cover were modelled using the Urban Multi-scale Environmental Predictor (UMEP) model. (Lindberg et al., 2018) The SOLWEIG module from UMEP was used to calculate mean radiant temperature (T_{mrt}) values for each point in the modelling domains. T_{mrt} is the average of radiant heat of an imaginary enclosure, a human body in this case. Using these values, a human thermal comfort index was calculated for each point in the domains at ground level (1.5m). The Universal Thermal Climate Index (UTCI) was calculated using the formula of Bröde et al. (2009), and UTCI equivalent temperatures and are corresponding to heat stress categories (from extreme heat to extreme cold stress category) (Bröde et.al., 2011).

The modelling was performed for 2pm on February 12, 2004, a typical hot summer day. On this hot modelled day, all the outdoor areas can be categorised as either under very strong or extreme heat stress. Breaking down the distribution of UTCI heat stress categories (Table 2) it is noted that the Existing scenario shows the lowest distribution of extreme heat stress temperatures (2.9%) while the BAU scenario shows the highest (35.8%). For the three water sensitive infill scenarios, Apartments and Combined show nearly identical distributions of extreme temperatures (12.8% and 12.9%) while the Townhouses scenario shows an increase (23.1%) of those extreme temperatures over the other two scenarios. Modelled results of UTCI for the five scenarios are presented in Figure 7.

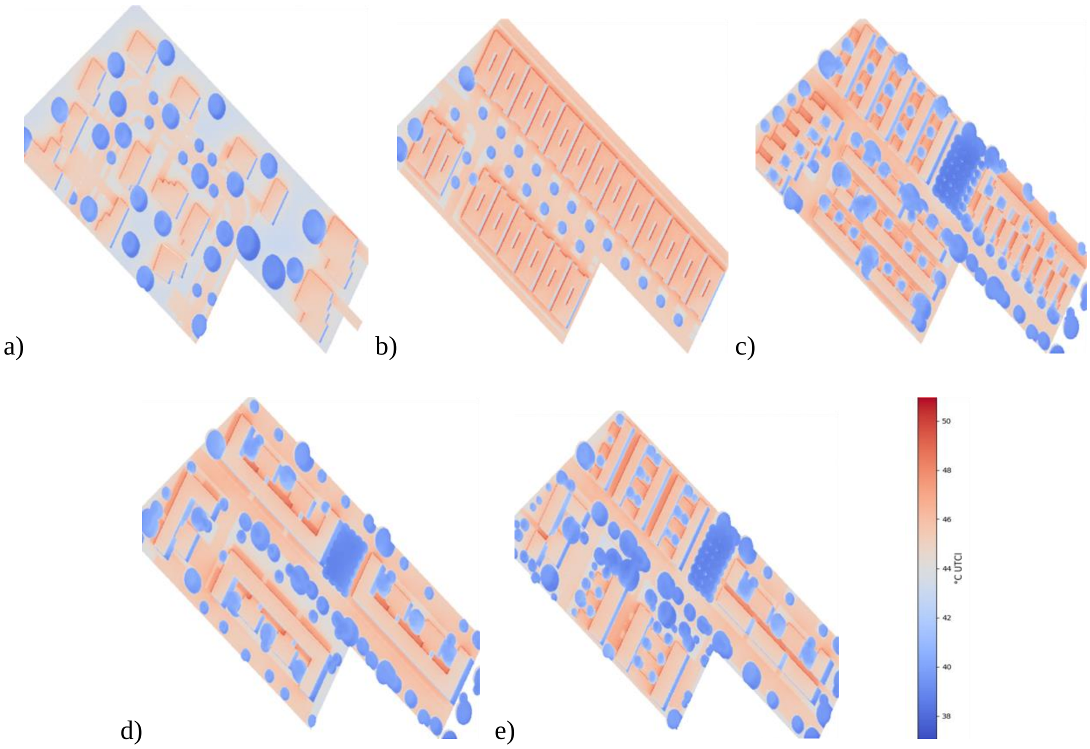


Figure 8: UTCI temperatures (degrees C) for five scenarios: a) Typical Existing; b) BAU; c) WS1 - Townhouses; d) WS2 - Apartments; and e) WS3 - Combined.

Table 2: Distributions of UTCI heat stress categories (in percentages) for selected scenarios: a) Typical Existing, b) BAU, c) WS1 - Townhouses, d) WS2 - Apartments, and e) WS3 - Combined. Heat stress categories based on Figure 8.

Scenario	Extreme	Very Strong	Strong
Typical Existing	2.9	97.1	0.0
BAU	35.8	64.2	0.0
WS1- Townhouses	23.1	76.9	0.0
WS2 - Apartments	12.9	87.1	0.0
WS3 - Combined	12.8	87.2	0.0

Key Design Principles for Water Sensitive Infill Designs

Proposed water sensitive infill designs have been informed by performance analyses demonstrated in previous segments and involve an iterative process of design, evaluation and redesign to achieve balanced outcomes. As a result of these analyses, the design variables that influence multiple performance objectives are observed with potential synergies and trade-offs that can work towards identifying the sweet-spots for dwelling design that optimise the benefits. These could include, for example:

- optimising building footprint/ roof surface for runoff mitigation against rainwater harvesting;
- optimising vegetated surfaces for evapotranspiration against increased water demand for irrigation;
- optimising higher occupancy for water efficiency against lower occupancy from more compact dwelling size.
- optimising the canopy cover, distribution and density for reduced heat stress

As such, features supporting water efficiency and hydrological flow, are crucial and represented across all categories used to evaluate architectural and urban space quality. For the reduced use of potable water for irrigation, for instance, it is proposed that dwellings be equipped with high quality water storage and recycling solutions, efficient and adaptable to the changing demands in the future. Similarly, outdoor spaces are to be treated with appropriate landscaping solutions and plant selection requiring minimal upkeep and irrigation. Permeable surfaces are to allow water infiltration in places where deep soil is not attainable, such as driveways, parking, play and other recreational areas.

Available outdoor space plays an important part in both stormwater and urban heat management, creating areas suitable for large canopy trees, infiltration and permeable surfaces. However, larger outdoor space may result in increased water and energy demand for irrigation and maintenance. One typical example would be large outdoor areas covered with lawn requiring high upkeep demands while making little contribution to the reduction of urban heat, especially in drier and hotter climates. The effective performance of available outdoor space is an outcome of design strategies increasing its usability/functionality. As such, thoughtful spatial organisation, with features related to efficient and compact design, is a key to delivering good outcomes, and is represented across all four architectural and urban qualities categories. The design exemplars in typologies catalogue show both internal and external spaces that are:

- multi-functional, adaptable to different uses and living arrangements,
- appropriately-proportioned, connected and positioned.

The overall quality of both indoor and outdoor spaces depends on its functionality and usability, which in turn depend on spatial organisation and design strategies that afford favourable use. Even though many aspects of the design could be quantified, analysis of urban and architectural characteristics is essentially a qualitative evaluation. As such, an ‘appropriately-proportioned’ courtyard could be defined by the ratio of its boundary lengths, where a square-shaped space supports more diverse uses and may be deemed more functional than a long narrow courtyard. An elongated space such as a linear park may be evaluated as ‘appropriately-proportioned’ as well when it supports its intended uses.

What follows is an account of the main principles and criteria used to asses quality of architectural and urban space contributing to high water and thermal performance. Architectural and urban space qualities are assessed on a ten-point scale against the criteria derived from the following principles:

Key Design Principles

1. Access to quality outdoor public space

Under the pressures of urban intensification and the requirements for more compact living at higher densities, provision and access to quality public realm, such as parks, reserves and plazas, becomes essential. With more public and shared amenity, activated street frontages increase the sense of safety and neighbourliness, and encourages walkability, reducing the high dependence on cars so prevalent in Australian suburbs.

Considered design strategies for residential precincts, with a range of suitable dwelling typologies allowing a diversity of household types, can complement and encourage use of nearby public open spaces. Higher densities and mixed-use typologies, with home/ work options, can generate additional services and amenities over time. This can include cafés, grocery shops, pharmacies and other small businesses, increasing use and passive surveillance of public spaces.

Public spaces designed to allow different ranges of activities maximise their use: for example, ‘slow’ streets may be used as access to residences, for bicycle connectivity and, as linear parks with generous tree canopy cover, allowing communal recreational activities in a pleasant and comfortable environment able to be occupied at different times of the day and year.

Pedestrian and cyclist-friendly infrastructure, including designated paths, bicycle racks, rest and recreational areas, reduce car dependence and carbon footprint while encouraging connectivity and utilisation of public open spaces.

Higher performing design strategies may be included in public spaces allowing precinct- scale solutions to stormwater and reduction of urban heat, benefitting whole precincts and also individual lots. This could include a precinct-scale water storage, recycling and re- use facility; a blue-green network that incorporates water elements in landscaping such as retention ponds and green swales.

2. Access to quality outdoor communal space

Consideration of shared amenity becomes significant in higher density infill development. To increase overall site amenity and reduce individual water and energy demands necessary for upkeep, shared BBQ, vegetable garden, play area, grouped car and bicycle parking areas may be included.

Efficient design strategies, including compact design and organisation of buildings on site, allow provision of quality communal spaces, functional, accessible to all residents, and adaptable to multiple uses. Certain common spaces, when well-designed, could serve multiple purposes: for example, shared driveways may also be used for play and other recreational activities.

To maintain a sense of privacy and individuality, while ensuring adequate sound and visual barriers, a balanced transition between private and communal spaces is important. Adequate setbacks, positioning of balconies and windows, choice of screens and fences, will help minimise overlooking from more activated street frontages.

3. Access to quality outdoor private space
This refers to the provision of courtyards, terraces, rooftop terraces, balconies and similar, providing good solar access, ventilation, outlook and sufficient soil and space for large canopy trees.

High quality outdoor private space is flexible and adaptable, designed to facilitate a variety of uses. Multiple use is supported when such spaces are considered in terms of their length and width, and the height of surrounding walls with their effect on sun and ventilation throughout the year. Courtyards adjacent to living and dining areas may be used as an extended living room, guest entertainment area, garden, and transitionary space between different house zones. An open carport may also be used as an outdoor space.

Landscaping solutions, including well-positioned large canopy shade trees, pergolas and trellises offer shade for improved thermal comfort, and can provide sound and visual privacy barriers when private areas face communal and public spaces.

4. Dwelling amenity and function
Water sensitive design strategies are utilised to deliver quality higher density living solutions, without compromising on amenity and function.

Building footprints are reduced and the number of floors increased in order to yield sufficient well-considered space for both private and communal outdoor areas on site, allowing more deep soil space to accommodate large canopy trees.

Reduction in parking space from the usual two car bays to one per dwelling makes additional usable space available. Further space is gained by grouping parking on site, and open car ports, grouped or individual, allow for permeable paving areas.

Flexibility in internal spatial arrangements is a crucial aspect in increasing usability, supporting a range of occupancies and adapting to changing requirements over time. Flexible internal space is designed to support a diversity of uses: for example, a room with separate services adjacent to a street could be used as a home office, games room or additional bedroom.
Internal spatial amenity and functionality is enhanced by direct physical and visual connection to quality outdoor spaces, achieved by designing living areas adjacent to courtyards, terraces and other outdoor areas.

Position and orientation of a dwelling on the site will improve overall site usability, thermal comfort and energy efficiency. Facing windows to the north and north-east will provide favourable solar orientation, and windows in two walls of a room will allow good cross-ventilation. Adequate shading from the direct sun on the east and west sides is achieved with well positioned greenery or by using a variety of shading systems. On unfavourably positioned sites, lightwells may be considered for access to natural light and breeze.

Conclusions
This paper presented recent results of an ongoing interdisciplinary study on water sensitive outcomes for middle suburban infill developments. As a part of this study a typologies catalogue was created with a selection of alternative models for the middle suburban infill development that support urban intensification and achieve high water sensitive performance outcomes. Typological models were selected for their overall design quality, enabling a high degree of amenity, adaptability, and response

to location. Designs and design scenarios are further developed and refined in an iterative design process, based on the preliminary multi-criteria performance analysis results.

As demonstrated on the Salisbury Site 1 case study, the typologies catalogue can be used as an evaluation tool. Represented typologies are used to design, test and compare different scenarios for the water sensitive outcomes in a nominated area. The analyses to date have shown the shortcomings of current industry practice infill models, which do not yield desired higher density and water sensitive outcomes. Similarly, the typologies catalogue can demonstrate the comparison of different water sensitive scenarios and designs possible. Improved performance outcomes are possible for within given areas and context. An important next step will be to generate performance results for the same typologies in different locations. This will help develop guidelines on how to define the urban systems to compare alternatives meaningfully, in different climatic conditions (i.e. Brisbane, Melbourne or Perth) to see if and how the influencing factors change in different environmental contexts.

Together with presented typologies solutions, a set of water sensitive design principles is defined, and as such this catalogue could be used to guide design and planning practice in the future.

Acknowledgements
The authors acknowledge the financial support of the Cooperative Research Centre for Water Sensitive Cities, and the valuable input from the Project Steering Committee of the IRP4 project. We are also grateful to the anonymous reviewers for useful comments.

References

Bowler, D. E., Buyung-Ali, L., Knight T. M., and Pullin, A. S. (2010) Urban greening to cool towns and cities: A systematic review of the empirical evidence, *Landscape and Urban Planning*, 97(3), pp.147-155.

Bröde, P., Fiala, D., Blazejczyk, K., Epstein, Y., Holmér, I., Jendritzky, G., Kampmann, B., Richards, M., Rintamäki, H., Shitzer, A. and Havenith, G. (2009) Calculating UTCI Equivalent Temperatures, in *Environmental Ergonomics XIII*, Proceedings of the 13th International Conference on Environmental Ergonomics, Boston, MA, 2-7 August 2009, University of Wollongong, Wollongong, pp.49-53. ISBN 978-1-74128-179-8

Bröde, P., Krüger, E.L. and Rossi, F.A. (2011) Assessment of Urban Outdoor Thermal Comfort by the Universal Thermal Climate Index UTCI, in Stylianos S. Kounalakis and M. Koskolou (Eds) *XIV International Conference on Environmental Ergonomics,* Proceedings of the 14th International Conference on Environmental Ergonomics, Nafplio, Greece, 2011, National and Kapodestrian University of Athens, pp.338-341. ISBN 978-960-489-272-3

Brunner, J. and P. Cozens (2013). Where have all the trees gone? Urban consolidation and the demise of urban vegetation: a case study from Western Australia, *Planning Practice and Research,* 28(2), pp.231-255.

Commonwealth of Australia (2017). *Australian State of Environment 2016*. Built Environment, Current Urban Planning and Management.

Coutts, A. M., Tapper, N. J., Beringer, J., Loughnan, M. and Demuzere, M. (2013). Watering our cities: The capacity for Water sensitive Urban Design to support urban cooling and improve human thermal comfort in the Australian context, *Progress in Physical Geography: Earth and Environment*, 37(1), pp.2-28.

Government of South Australia (2017) The 30-year plan for Greater Adelaide - 2017 update. Adelaide: Department of Planning, Transport and Infrastructure.

Jacobson, C. R. (2011). Identification and quantification of the hydrological impacts of imperviousness in urban catchment. *Journal of Environmental Management,* 92(6), pp.1438-1448.

Lam, K. L., Moravej, M., Renouf M. A., and Kenway, S. J. (2019). Urban Water Mass Balance (UWMB) tool V1.10, Cooperative Research Centre for Water Sensitive Cities.

Lindberg, F., Grimmond, C. S., Gabey, A., Huang, B., Kent, C. W., Sun, T., Theeuwes, N. E., Järvi, L., Ward, H. C., Capel-Timms, I., Chang, Y., Jonsson, P., Krave, N., Liu, D., Meyer, D., Olofson, K. F. G., Tan, J., Wästberg, D., Xue, L. and Zhang, Z. (2018) Urban Multi-scale Environmental Predictor (UMEP): An integrated tool for city-based climate services, *Environmental Modelling and Software,* 99*,* pp.70-87. ISSN 13648152, doi: 10.1016/j.envsoft.2017.09.020.

London, G., Bertram, N., Sainsbury, O., and Todorovic, T. (2019) Infill Typologies Catalogue - DRAFT for consultation. Melbourne, Cooperative Research Centre for Water Sensitive Cities. Available from https://watersensitivecities.org.au/.

Murray, S., Bertram, N., Ramirez-Lovering, D., Khor, L. A. and Meyer, B. (2011) Infill Opportunities, Design Research Report (Melbourne: Office of the Victorian Government Architect).

Newton, P., Newman, P., Glackin, S. and Trubka, R. (2012) Greening the greyfields: Unlocking the redevelopment potential of the middle suburbs in Australian cities, *World Academy of Science, Engineering and Technology*, 71, pp.138-157.

Newton, P. and Glackin S. (2014) Understanding infill: Towards new policy and practice for urban regeneration in established suburbs of Australia's cities, *Urban Policy and Research,* 32(2), pp.121-143.

Renouf, M. A., Serrao-Neumann, S., Kenway, S. J., Morgan E. A. and Low Choy, D. (2017) Urban water metabolism indicators derived from a water mass balance – Bridging the gap between visions and performance assessment of urban water resource management, *Water Research,* 122, pp.669-677.

Renouf, M. A., Kenway, S. J., Bertram, N., Sainsbury, O., London, G., Todorovic, T., Pype, M. L., Nice, K. A., Sochacka, B., Moravej, M., Tara, N. and Martin, D. (2019) Infill Performance Evaluation Framework - DRAFT for consultation. Melbourne, Cooperative Research Centre for Water Sensitive Cities. Available from https://watersensitivecities.org.au/.

Thomson, G., Newton, P. and Newman, P. (2017) Urban regeneration and urban fabrics in Australian cities, *Journal of Urban Regeneration and Renewal*, 10(2), pp.169-190.

Wong, T. H. F. and Brown, R. R. (2009) The water sensitive city: principles for practice, *Water Science and Technology*, 60, pp.637-682.