sustainability
MDPI

Article

East Village at Knutsford: A Case Study in Sustainable Urbanism

Joshua Byrne [1], Mike Mouritz [1], Mark Taylor [2] and Jessica K. Breadsell [1,*]

[1] Curtin University Sustainability Policy Institute, Curtin University, Perth, WA 6845, Australia; joshua.byrne@curtin.edu.au (J.B.); mike.mouritz@curtin.edu.au (M.M.)
[2] Josh Byrne & Associates, Fremantle, WA 6160, Australia; mark@joshbyrne.com.au
* Correspondence: jessica.breadsell@curtin.edu.au

Received: 14 June 2020; Accepted: 4 August 2020; Published: 5 August 2020

check for updates

Abstract: With increasing pressure to ensure that sustainability features in homes are commercially viable, demonstration projects are vital to highlight the real-world challenges and opportunities for innovation. This paper documents the incorporation of sustainability objectives into the "East Village at Knutsford" residential "living laboratory" development, within the Knutsford urban regeneration precinct, approximately 1.5 km east of the Fremantle central business district in Western Australia. The sustainability objectives for the project include being a "Net Zero Energy Development" using 100% renewable energy and maximizing the self-supply of energy, reducing mains water consumption as much as is practical, and using the landscape design to complement these objectives without compromising a best-practice urban greening outcome. The paper documents the design initiatives and strategies that have been included to achieve these objectives in a commercially viable project and the results of modelling where it has been used to test the design against the objectives to ensure their validity. The key features that have been incorporated into the townhouses component of the development are outlined, illustrating integrated design and systems thinking that builds on previous demonstration projects, incorporating solar energy storage and electric vehicle charging plus significant mains water savings by adopting water-sensitive features in the homes and the within the private and public gardens. The expected grid energy and mains water consumption levels in the homes through modelling compared to the metropolitan average is 80% lower. The project is presented as an important step in the application of available technologies and design features to meet stated sustainability objectives, highlighting the benefits of an embedded living laboratory research approach.

Keywords: sustainable urbanism; energy efficient homes; solar energy storage; WSUD; low-carbon living; living laboratory

1. Introduction

1.1. Background

With increasing pressure to reduce greenhouse gas emissions around the world, the built environment has a large role to play, as highlighted through the United Nations (UN) Sustainable Development Goals (SDG) [1]. Buildings account for nearly 40% of annual global energy use and approximately 30% of greenhouse gas emissions through their life cycle [2]. The call from the UN SDGs for cities to be carbon neutral and the integration of nature-based solutions to improve environmental health, urban amenity and community wellbeing can be demonstrated through innovative case study projects in our cities; some Australian examples are highlighted in the literature [3]. Sustainable urbanism projects that highlight how to decarbonize energy systems, increase stormwater and wastewater treatment and reuse, and improve urban design quality to increase liveability and wellbeing are necessary to highlight the viability of these objectives [3]. These processes are long-term and require complex transitions in multiple infrastructure systems including energy, water and urban design approvals processes [3]. Governments in Australia have set targets of net zero carbon emissions in the built environment sector by 2050, which will require significant efforts by developers, researchers and governments to reach.

With urbanization increasing the number of buildings in our cities, there is an opportunity to construct energy-efficient and climate-sensitive dwellings to provide diverse housing options and reduce climate impacts [4]. In Australia, 90% of population growth is absorbed into cities, often resulting in large greenfield developments away from city centers and long commute times for residents [5]. Infill development, on the other hand, can provide housing close to existing services and amenities and offer housing diversity through good planning and design [6]. While there are infill targets set by state governments to address the issues of urban sprawl in Australia cities, targets are often not reached. For example, in Perth, Western Australia, the State Government infill target of 47% of all new developments is not being reached, with only around 30% of new developments occurring in infill areas [6]. The strategic development of brownfield sites contributes to reducing urban sprawl, revitalising urban areas and providing an opportunity for the demonstration of housing innovations [7,8]. Energy-efficient and low-carbon buildings are leading this movement through showcasing realistic features that can be incorporated into new homes and buildings [9,10]. This has begun through the uptake of rooftop solar photovoltaic (PV) systems by households throughout the world. In Australia, 20% of households now have rooftop solar PV systems, while in the South West Interconnected System, which includes the Perth metropolitan area, it is nearly one in three households [11,12]. Battery storage systems are forecast to be the next innovation to of the transition the electricity system [11,12]. However, the performance of these systems can be varied, based on factors such as the performance PV panels, the household demand, onsite shading and local climatic factors [13,14].

In tandem with these developments occurring, the rise of "smart cities" that incorporate interconnected digital technologies is also assisting homes and cities in maximizing energy efficiency and reducing greenhouse gases [15]. Smart urban systems and processes that can support individuals, households and cities in managing energy and resource use are vital to furthering regenerative cities [3]. Real-time metering and the associated processing of data are useful for identifying areas of improvement [16]. However, the successful deployment of these systems is dependent upon each part working effectively [17].

Innovative infill developments also provide an opportunity to address concerns around sustainable water use in households. Approaches to efficient and sustainable uses of water in homes can be addressed through Water-Sensitive Urban Design (WSUD) principles [18,19]. This aims to integrate water management into the urban form through the consideration of stormwater infiltration and runoff, alternative urban water supplies and biophilic urban design considerations [20]. These approaches use rainwater and stormwater harvesting, and greywater and wastewater collection and treatment to reduce dependence on centralized sources of water [21]. As cities, particularly Perth (which has faced significant climate change), continue to grow in size, resilient water supplies are needed to meet demand in a drying climate [22]. In this context, WSUD has become a key strategy to help develop liveability and the water system resilience necessary to deal with these challenges [23].

1.2. Living Laboratories

Sustainable urbanism, energy efficient homes, smart cities, WSUD and infill projects have been demonstrated through experimental intervention projects termed "living laboratories" [8,24,25]. These represent sites that allow stakeholders to design, test and learn from innovations in real time [25]. The participation of various stakeholders, experimentation of innovative development guidelines, technology and consolidation of learnings are key aims [8]. This can occur through embedding projects within a socio-spatial context, scaling innovations into a broader context or translating lessons learned to different contexts [8]. "Embedded living laboratories", those that are based in a real-world context with associated commercial and legislative considerations, are the ideal place to observe and learn about occupant resource consumption, co-create innovative solutions to problems with a variety of stakeholders and test innovative technologies or approaches [26].

This paper outlines a case study of an embedded living laboratory whereby an active demonstration of sustainability innovations and design objectives are investigated. This process, commenced at the design stage, involved collaboration with key stakeholders relating to the design process that highlights how establishing networks and sustainable design principles from the beginning of a project can influence the outcomes of a residential development [27]. The conception and planning stage is influential in any house or development project, let alone those with sustainable innovations [28]. Various stakeholders with competing interests and different focuses for sustainable innovations are influential, and in some cases, those professionals with a relevant understanding of design and sustainability innovations are left out of this process [29]. Decisions made during the concept and planning stage affect the construction and occupancy stage of the development and, as such, require analysis to identify aspects of importance to furthering sustainable households and precincts [28,30]. An embedded living laboratory provides an opportunity to undertake this research, as has been done in previous projects [10,31].

1.3. Case Study

"East Village at Knutsford" (EVK) is an embedded living laboratory residential development within the Knutsford urban regeneration precinct, approximately 1.5 km east of Fremantle in Western Australia. The project is located on a 1.5 ha site and consists of 36 townhouses established within a survey strata framework plus two adjoining apartment sites for an expected total of around 100 dwellings once completed. It represents a leading-edge example of sustainable urbanism—incorporating passive solar design and integrated energy and water systems—illustrating an approach to low-carbon living and water-sensitive features that is commercially viable. The project is being delivered by the Western Australian State Government land development agency, DevelopmentWA, and builds on a body of knowledge and experience developed over a number of years—starting from case study projects that explored (theoretically) the potential benefits of these approaches in the 1990s [19] to on-ground examples designed, delivered and reported on extensively in the past decade [10,21,32,33].

The sustainability objectives for the project include being a "Net Zero Energy Development", which is defined as using 100% renewable energy, maximizing the self-supply of energy through solar PV systems and battery storage, reducing mains water consumption as much as is commercially viable and using the landscape design to complement these objectives without compromising a best-practice urban greening outcome. The paper documents the design initiatives and strategies that have been included to achieve these objectives and the results of modelling where it has been used to test the design against the objectives. Although these principles are widely discussed and recommended in the literature, demonstration projects that are commercially viable are limited. This paper's uniqueness comes from highlighting the aspects of the design process, including the testing of the modelled performance, to ensure these objectives can be met.

This paper initially documents the key design features before outlining the modelled results—which provide the benchmark for monitoring as the project is completed and occupied. Importantly, we also highlight the challenges associated with delivering innovative projects that are outside of the current development model in a bid to illustrate pathways for transferring the insights gained into innovations at scale. Finally, this paper compares the various sustainability innovations at EVK with those of another local exemplar urban development project, the "WGV" precinct, located in the suburb of White Gum Valley [10,34], to illustrate how it represents a transition step in progressing the sustainable urbanism agenda [35]. The WGV precinct also had similar sustainability objectives; however, the results during occupation have been varied [33,36].

At the time of publication, the civil and landscaping works for EVK were complete, including the installation of energy and water services, water sensitive urban design features and monitoring infrastructure, and the project had recently been recognised as a global leader in sustainability under the One Planet Living program [37].

2. Methods: Development Design Features

This section presents the key design, delivery, energy, water and landscaping innovations incorporated into the EVK project. Emphasis is placed on the site-level initiatives, which are already built, and the 36 townhouses, which are fully designed and are soon to be constructed. The key innovations are highlighted with the aim of illustrating the integrated nature of the overall approach to development. It illustrates how by adopting a systems approach—which brings together a developer with a clear intention to innovate, with a team of skilled designers across a range of fields including architecture, landscape architecture, engineering and sustainability—the design challenges are gradually and creatively solved.

2.1. Development Intention

As the Western Australian Government land development agency, DevelopmentWA is charged with the responsibility for delivering a range of urban and industrial land development projects across the state. EVK is part of DevelopmentWA's commitment to its "Innovation through Demonstration" program [38]. The project builds on learnings and experience from previous projects such as the nearby "WGV" residential infill precinct [10,32,33,36,39–42] and aims to deliver a leading-edge example of sustainable urbanism. In particular, this project extends the so-called Citizen Energy Utility (or Energy Governance Model) [41] developed at WGV for apartment complexes and applies the model within a survey strata complex of 36 townhouses to manage solar power, battery storage and local water systems.

The key sustainability objectives of the project include:

- Net Zero Energy Homes that produce more energy than they use over an average year, while achieving high levels of comfort and amenity. These will be all-electric homes, with no reticulated gas supply being connected to the development.
- A Net Zero Energy Development, meaning that the annual average energy production at EVK should exceed the annual average consumption.
- A 100% renewable energy development, meaning that all electricity used onsite is to be from renewable sources. This includes onsite energy systems (in this case, rooftop solar photovoltaic systems) and electricity sourced from the grid. Because there is no renewable gas supply available to the site, or more widely, and because there is never likely to be such a supply, gas connection was ruled out.
- A largely energy-self-reliant development, meaning that dwelling and common services energy requirements are sourced from onsite generation systems as much as is practical and commercially viable.
- An Electric Vehicle (EV)-ready development that allows for the home charging of EVs. The electrical design allows for vehicle charging at the high end of home-charging rates, and the energy requirements of EVs have been considered in the setting of the targets and objectives for the project (with provision for electric bicycles and scooters as part of the overall strategy).
- Reducing reliance on mains water supply as much as is practical.
- A landscape design that supports the above objectives while also achieving best practice in urban greening, including seasonal shading, food production and wildlife habitats.

The design process sought to incorporate initiatives and strategies to achieve the above objectives.

2.2. Delivery Innovations

The project created a design for 36 townhouses as an integrated package of built form within the property title framework of "survey strata" [43,44], which has a specific meaning in Western Australian property law. The survey strata structure allows the properties to be designed so that common services such as sewerage, water and power can be shared, as well as there being common property that is part of the development. The structure allows for the ongoing management of the innovations designed to become the responsibility of the strata management company that will be owned by the future purchasers of the homes. The innovation here was the use of the survey strata structure to enable the management of shared service infrastructure, such as a groundwater bore that services both the private and common landscape spaces, and an embedded energy network; both of these are initiatives that would meet regulatory and governance barriers if the dwellings at EVK were on independent, privately owned lots.

2.3. Built Form Innovations

A Fremantle-based architectural company designed the homes, undertook the site planning and obtained development approval for the 36 townhouses as part of the survey strata subdivision. It is important to note that in Western Australia, for a survey strata subdivision, the built form is generally required to be resolved at the stage of subdivision application, which is not usually required for a "green title" (freehold) subdivision. The architecture leverages learnings from a nearby development that embraced compact, efficient urban design [45]; however, a unique theme developed by the architects involved utilizing alternative materials and colour schemes in a bid to respond to the built form character requirements of the local precinct, which has a mixed-use and industrial warehouse vernacular. The townhouses have been designed to be climate responsive and incorporate integrated renewable energy and local-scale water systems. Public and private greenspaces are linked to provide open space, shade and connectivity.

The typical lot layout for the townhouse involved 9 m- and 7 m-wide by 28 m-long sites in a generally east–west configuration as presented in Figure 1. The designs are referred to as an "upside-down house" typology, with the main living area on the upper floor, which maximizes winter sun for passive heating as shown in Figure 2. This configuration reduces the need for mechanical heating in winter whilst ensuring access to prevailing summer breezes for natural cooling in the warmer months. Twelve of the thirty-six townhouse are configured with a large "flexible" space on the ground floor with the intention that residents have a suitable space for home-based businesses. These spaces have the potential for a somewhat separate access from the street to allow a functional mix of domestic and business activities. Another twelve of the townhouse designs come with a pre-approved option for an additional, separate living space that might suit an aging relative or an adult child still at home or could be leased out to tenants. These spaces, sometimes known as "Fonzies", increase the diversity of housing available at EVK, providing access to those not in the market for a three-bedroom, two-bathroom home.

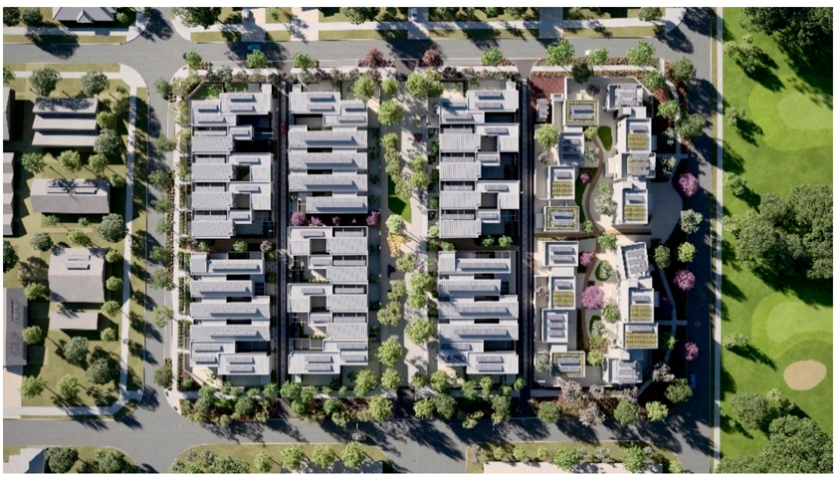

Figure 1. Layout of the 36 townhouses (as designed) at the development site, plus two apartment sites (indicative only). Source: DevelopmentWA.

Figure 2. North-facing living areas are located on the top floor to ensure solar penetration in winter for good thermal performance. Source: DevelopmentWA.

2.4. Energy Innovations

The energy system design process included comprehensive energy modelling to test outcomes and determine optimal sizing, particularly for PV and energy storage systems. Energy loads were calculated on the basis of the homes meeting a 7.5-star Nationwide House Energy Rating Scheme (NatHERS) rating [46], the use of energy efficient appliances and an assumption of 30% uptake of home electric vehicle charging. The final sizing resulted in the inclusion of a 6.6 kW PV panels on each of the dwellings (with a 5 kW inverter), connected to an onsite shared 670 kWh battery. The battery has been configured to import and store electricity for the purpose of minimizing the electricity consumed from the grid. The system allows for trading between the householders and battery operator [47] with transactions being recorded using a blockchain platform [42,48]. The advantage to the EVK homes remaining connected to the grid is the assurance of energy security in the case of system faults and allowing for energy trading across the grid to occur [42].

Modelling to Verify Energy Strategies

Energy modelling was used to verify that the design was likely to meet the stated objectives for the project. In most building codes adopted across jurisdictions, building energy performance is calculated through simulation software [49], which projects energy use during the building operational stage based on assumptions of occupancy, behaviour, technology operation and maintenance, and climate. Building design, construction techniques and materials are also modelled at this instance to enable the building in question to meet set targets. Two tools were used to verify these results:

- The NatHERS tool is used as a standard compliance pathway for dwellings to comply with the energy efficiency requirements of the Australian National Construction Code but can also be used to analyse designs and identify opportunities to improve performance or required changes to achieve a target.
- Precinct energy modelling: A bespoke energy model was developed to allow detailed scenario analysis and to be able to test a variety of financial models. The parameters were then run in the HOMER platform (developed by the US National Renewable Energy Laboratory) to confirm that the key results were consistent.

2.5. Water Innovations

In addition to the use of water-efficient fixtures and appliances, each of the 36 townhouse sites has a 7000-litre rainwater tank installed, located beneath the future carports. The tank sizing is supported by daily time-step supply–demand modelling [50] to optimise their value in Perth's Mediterranean climate in relation to their cost and also in terms of the energy intensity of the construction and installation, whilst also responding to the realities of space constraints. Water from the rainwater tanks will supply the toilets and washing machines, which is the safest way in which to use rain that comes off roofs, similar to other projects such as the nearby WGV precinct [21]. In addition, the rainwater will supply hot water demands, including showers, following heat treatment by electric-heat-pump hot water systems, which will have their heating cycle programmed to operate using available surplus solar energy. This approach supplements the scheme water supply to the highest indoor water use in Perth homes, the hot water service [51]. In the Perth context, as the house blocks become smaller and the proportion of garden water use reduces, it makes it good sense to start focusing on providing fit-for-purpose alternate water sources indoors as well.

A strata groundwater bore has been installed as a non-drinking water supply for the landscape irrigation of both public and private gardens. The strata bore will be owned and operated by the strata company and abstracts groundwater from the superficial aquifer at a depth of around 40 m. Importantly, the strata bore is using groundwater that is being recharged through locally harvested and infiltrated stormwater. All rainfall events, including the 100 year Average Recurrence Interval (ARI) rainfall events, are retained on site. In addition to providing water for irrigation, the reticulated strata bore supply also provides for hand watering via designated garden taps on each lot. This simple, but important, measure means that no mains water is required outside the home, representing a progression from the nearby WGV precinct community bore scheme (which is operated by the local government authority as a service provider) where WA State Government public health guidelines restricted its use to supplying fixed irrigation systems only. The ability for a shared groundwater scheme to be used via taps at EVK is attributed to the fact that the scheme will be managed by the strata company, which ultimately takes responsibility for its management and risks.

The overall approach to stormwater management within the development is in line with the principles of WSUD [19] where light rainfall events are directed into the soil close to where the rain lands through a combination of permeable paving, rain gardens and swales. These flows go into the subsoil and recharge soil moisture, to be used by trees and other plants within landscaped areas. Bigger rainfall events are directed into shallow infiltration galleries, dispersed throughout the site, which recharges the groundwater. The intended outcome is a positive recharge to the groundwater, allowing for the sustainable managed extraction of the groundwater for irrigation, even in Perth's drying climate [21].

2.6. Landscaping Innovations

Public realm landscaping is an integral part of the development. As this is a former industrial precinct, there were no trees on the site; therefore, the project seeks to be an example of regenerative landscaping. This involved transforming a barren site that had required remediation following the previous use as a depot, into one that, once established, will provide shade for cooling and habitats to support urban wildlife as well as local food production opportunities for residents and the surrounding community.

As a strata development, the shared landscape spaces including streetscapes, lane ways and public access ways will be managed by the strata company. This allows for greater flexibility in design than would otherwise be possible in a traditional green title development setting where the local government authority plays a key role in approving the landscape design on the basis that they will eventually take over management and upkeep.

The target is to achieve a 30% tree canopy coverage across the site once mature; this exceeds the City of Fremantle target, where EVK is located, of 20% [52].

Through the careful positioning of trees, there will be no shading of the solar panels. Tree selection includes the use of deciduous trees where summer shade and winter light penetration requirements are important, as well as evergreen native species where winter shading is not an issue. Around a third of the trees are edible fruit and nut trees. There are also extensive understory plantings along the street verges to provide amenity and biodiversity benefits.

The homes and courtyard spaces interface thoughtfully with a network of public access ways, providing good permeability through the development and to the surrounding neighbourhood. The landscaped areas also incorporate seating and barbeque facilities, as well as public art. The laneways and main street have been designed to be shared spaces, reflected in the surface treatments, flush kerbing and incorporation of planting, furniture and amenity lighting.

3. Results: Modelled Performance

The design process involved the modelling of energy and water performance by the design team to allow for the evaluation of technical options during the design development process. Furthermore, the overall development was modelled independently [53] to assess and compare the predicted performance [54]. The results of these processes are outlined below.

3.1. Energy

Energy modelling based on the design, servicing and fit-out assumptions included the following items that tend to increase modelled energy consumption compared to assessing business-as-usual independently owned housing lots:

- Common lighting and water pumping loads.
- Electric vehicle charging loads.

Three main performance improvement elements of the project were included in the energy modelling:

- Dwelling design and systems choices, such as the 7.5-star NatHERS rating [46] and the use of efficient appliances, including air-sourced heat-pump hot water systems and induction cooktops, reducing electricity requirements by around 35% from the local average.
- Solar PV systems meet loads directly while the sun is shining and, because of the embedded network, energy can be exported directly to neighbours. Electricity imports are reduced by up to 26%. Without a battery, around 60% of the PV electricity generated on site would be unused and typically exported to the grid, if such feed-in was permitted.
- The battery system enables the renewable energy produced on the site to be stored and drawn on when required by households within the embedded network. Grid reliance is expected to be approximately 20% in winter months.

Electricity exports exceed imports by approximately 17%, meeting the commonly used definition of a “Zero Energy Development” in that more onsite energy is produced than is consumed annually on average. Furthermore, a supplier agreement has been entered into with a local energy retailer to ensure that any electricity imported from the grid is generated from renewable sources.

The impact of the energy-related initiatives at EVK referenced against the Perth local average on a household-per-annum basis is presented in Figure 3.

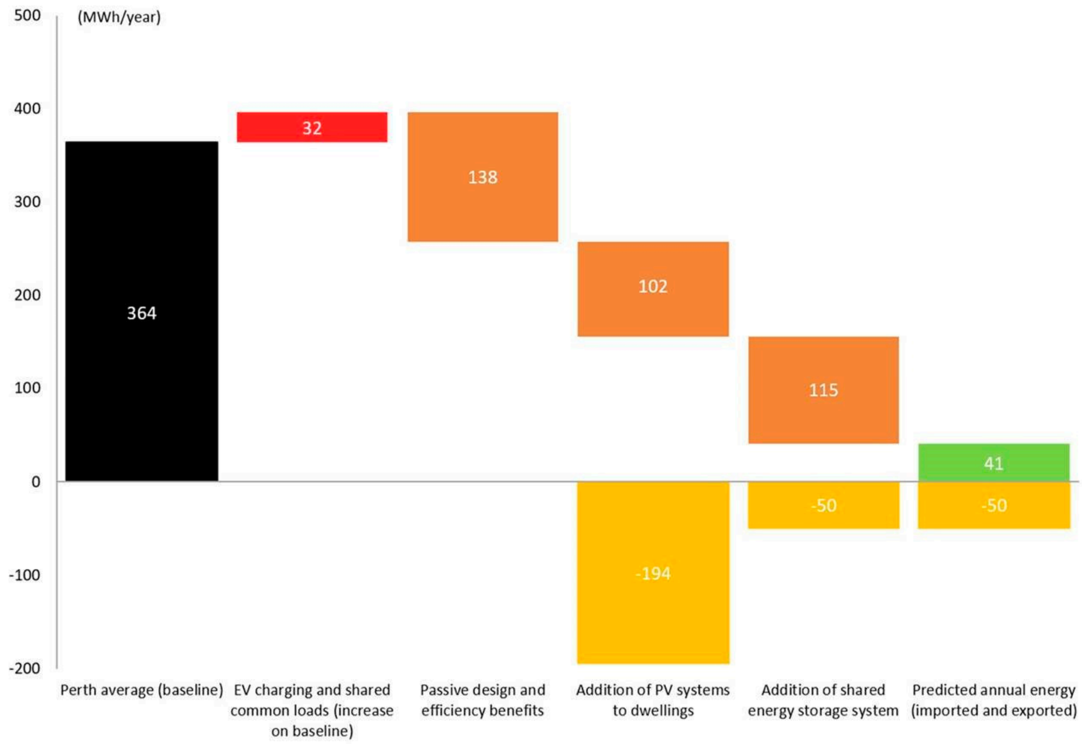

Figure 3. Expected annual household energy reductions against Perth average base line. Source: [55].

3.2. Water

A detailed water balance was prepared as part of the option analysis process undertaken to develop the water system design for the precinct and the townhouses. Modelling was used to determine the impact of various mains water saving measures, referenced against the Perth local average [51], using a bespoke spreadsheet tool with savings based on local precedence [21]. The modelled per-person reduction of mains water consumption is established as being in the order of 80%. The savings are attributed to:

- Savings in the order of 25% brought about through reduced lot sizes compared to the Perth average resulting in reduced irrigation volumes.
- Improved water-use efficiency, including better-performing internal water fixtures and efficient irrigation, as well as efficient water-use behaviour and leak detection supported by smart metering, leading to a further 25% reduction.
- The use of alternate water sources including rainwater and sustainably managed groundwater to substitute mains water by around 30%.

The impact of the initiatives is presented in Figure 4 against the Perth average on a per-person basis.

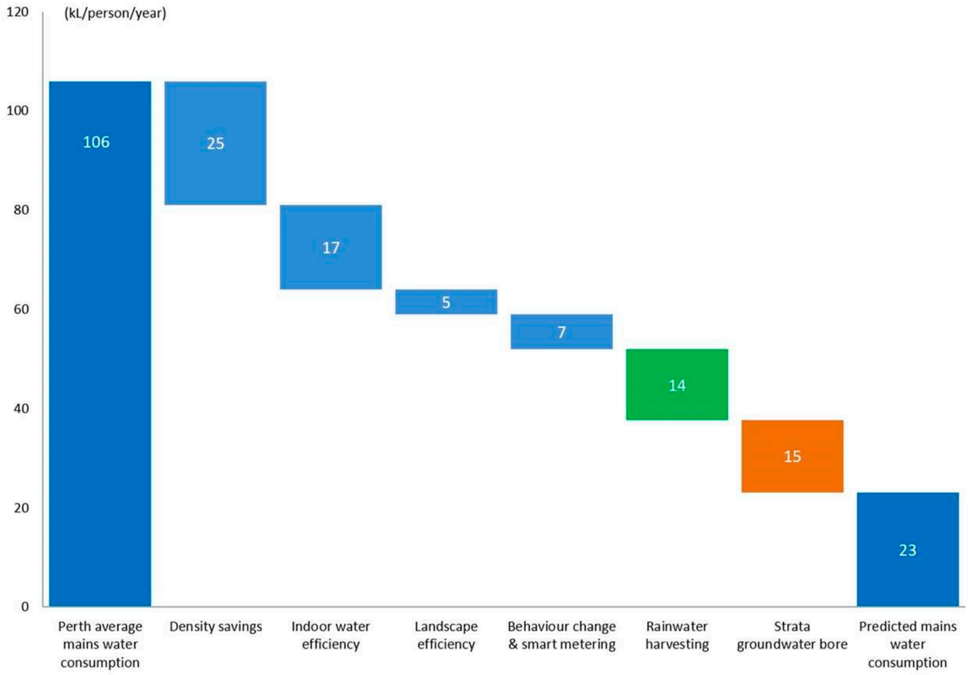

Figure 4. Expected annual mains water reduction on a per-person basis against the Perth average baseline. Source: [56].

3.3. Cost Comparisons

A cost compassion process was undertaken as if the project had been designed and delivered in traditional development configuration [45]. The cost comparisons illustrated the benefits of the design innovations incorporated in this development, with the comparisons made with an equivalent green title subdivision of a comparable configuration to the 36 townhouses being developed as survey strata complexes with all the innovations as documented. It is important to note that a direct comparison of cost is not always straightforward because an alternative design has alterative assumptions; however, the analysis of costs illustrated that apart from the battery cost, which was subsidized, capital expenditure was estimated to be equal to or comparable to that for typical comparable development.

4. Discussion and Conclusions

As identified earlier, EVK is building on prior learnings from other sustainability leadership projects undertaken by DevelopmentWA, most notably the highly awarded WGV precinct. This process, conducted as part of DevelopmentWA's Innovation through Demonstration program, helps to build industry confidence and capacity, which is required to implement the types of initiatives discussed at scale.

Table 1 lists the energy and water initiatives deployed at both the WGV precinct and EVK, showing the progression of measures in support of improved performance. The initiatives listed for the WGV precinct relate to the detached house product at that development (as opposed to the apartments) for the relevance of comparison to the EVK townhouses. As shown in Table 1, post-occupancy research on detached lot energy and water use at WGV verified that performance targets established during the design phase were not met although the figures were significantly better than local "Business as Usual" benchmark figures, with an approximately 50% reduction in energy and water use, and the houses exporting more energy than they used over the course of the year [33]. Further work is required to fully understand this discrepancy. Furthermore, the nature of the monitoring set-up, which was provided by multiple service providers, made definitive analysis challenging. In particular, when energy and water usage values varied from what was expected, it was difficult to determine whether the cause was due to technology failure (e.g., rainwater pumps failing), user behaviour or, in some cases, the quality of data due to malfunctions in data collection. The intentional inclusion of live-work configurations in the homes at EVK is anticipated to have an influence on the energy and water use of the households. As was shown at the WGV precinct, some households with residents working from home have different resource consumption patterns, which can take advantage of energy generated during the day by the solar PV systems to minimize battery or grid draw in the evening peaks [36]. Therefore, the targeted monitoring of household energy and water load draws at EVK will help further the understanding of the influence that daily work routines have on household energy and water resource consumption, along with improving the system of monitoring devices [36,57,58].

At EVK, a comprehensive embedded network sub-metering system has been installed for billing purposes and data visualization for residents, and data collection for researchers to verify the performance targets of the townhouse and precinct systems. Figure 5 provides a schematic of the metering system and how the information collected flows through to end users.

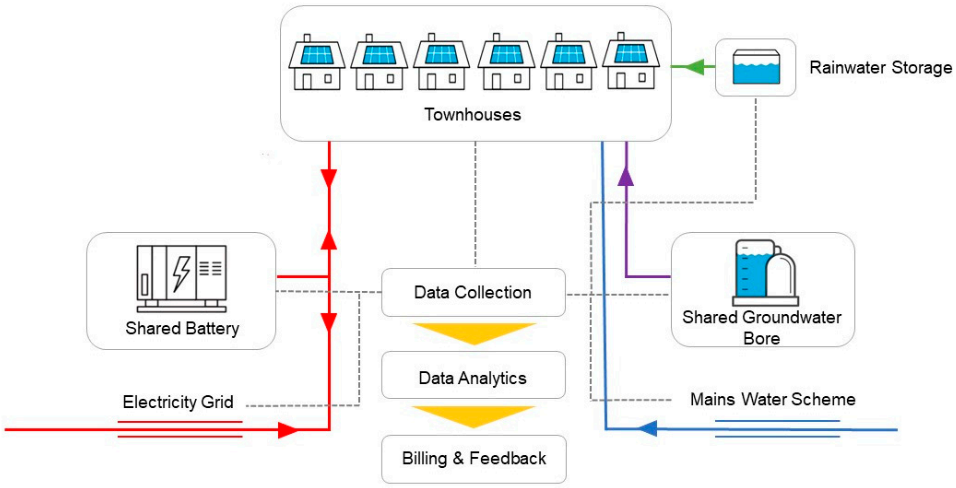

Figure 5. Data collection, analytics, billing and resident feedback. Source: adapted from [59].

House meters include bi-directional energy meters on the main house electrical supply connection as well as meters on the PV system to capture solar generation. The bi-directional meters will enable the tracking of the importing and exporting of electricity between each townhouse and the shared battery, with this process, and the associated debits and credits undertaken by the battery owner–operator using a blockchain platform [33,60]. Water meters installed on the mains water and strata groundwater bore connection to each house enable the proportionate billing of households for their water use by the strata company. Rainwater meters have been installed to understand the impact of this source in reducing mains water reliance.

It is anticipated that this robust metering system, which includes functionality for system checks for reliable management, will enable more reliable enquiry into any variations between As Designed and As Operated performance metrics and, as such, be of great value to industry and researchers alike who are interested in knowing how to close this gap [61].

Residents will also have access to a dashboard to track their household (and precinct level) energy and water consumption levels. This dashboard can be accessed via the Internet on any device, eliminating the obstacle of previous smart metering devices, which may only accessible from the home [62]. Previous work has examined the use of dashboards by participants in an earlier living laboratory project in a suburb-wide trial of the technology within the City of Fremantle [42]. Post-occupancy evaluation will determine the engagement with and usefulness of this technology for the residents of the development. A key component of smart cities' effectiveness is efficient communication [15], and it is hoped that this dashboard will contribute to this. It is acknowledged that this increases the number of actors involved in data management and governance, which is an area of research that is outside the scope of this paper but has been discussed by others [42,63].

Table 1. Comparison of energy and water initiatives between the WGV precinct and "East Village at Knutsford" (EVK). Source: authors.

ENERGY INITIATIVES	WGV	EVK
NatHERS rating *	7 star minimum	7.5 star minimum
Reticulated natural gas	Yes (optional connection)	No
Minimum solar PV per dwelling	1.5 kW min. Upgraded to 3.5 kW via developer sustainability package	6.6 kW PV with 5 kW inverter packaged with fully designed homes
Battery for energy storage	No site-level shared battery system	Shared 670 kWh battery for 36 townhouses and common services
Hot water	Solar Hot Water System or heat-pump water heater	Heat pump (5 star) packaged with fully designed homes
Air conditioning	Reverse cycle (3 star ** min.)	Ceiling fans installed in living areas No AC provided—can be added by owner if desired
Cooking	Not specified	Induction cooktop Electric oven
Electric Vehicle charging	Not specified	Dedicated circuit for home charging, plus public fast charger
Smart metering	Research phase only	Permanent strata owned embedded, remotely read metering network
Drying court	Mandatory	Provided
Shade tree	Deep root zone mandatory; tree provided via developer sustainability package	Provided
Lighting	LED or compact fluorescent	LED
MODELLED ENERGY USE REDUCTION	80%	80%
ACTUAL ENERGY USE REDUCTION	54% + 20.5 kW/day export	To be verified once occupied
WATER INITIATIVES	**WGV**	**EVK**
Water-efficient fixtures beyond minimum compliance (using WELS *** ratings)	Yes Shower heads: 3 star (max. 7.5 L/min) Toilets: 4 star min. All other taps (exc. outdoor and bath): 4 star min.	Yes Shower heads: 3 star (max. 7.5 L/min) Toilets: 4 star min. All other taps (exc. outdoor and bath): 4 star min.
Water-efficient landscape requirements	Yes, including drip irrigation to garden beds, low-water-use plants, irrigation controller and soil conditioning	Yes, though likely to have greater control of outcomes as the landscape and irrigation installations will be installed by the builder

* Nationwide House Energy Rating Scheme. ** Equipment Energy Efficiency program. *** Water Efficiency Labelling and Standards scheme.

Table 1. *Cont.*

WATER INITIATIVES	WGV	EVK
Rainwater harvesting	Dual plumbing required for toilet and washing machine, with min. 70 m^2 roof catchment available to tank location; 3 kL tank plus pump and controls provided via developer sustainability package	7 kL tank installed and connected to toilet, washing machine and hot water service; entire roof catchment connected (average 150 m^2)
Shared non-drinking water supply (groundwater)	Community bore for irrigation only	Strata groundwater bore for irrigation and garden taps
WSUD stormwater controls	Yes	Yes, but more comprehensive due to strata ownership
MODELLED MAINS WATER USE REDUCTION	70%	80%
ACTUAL MAINS WATER USE REDUCTION	48%	To be verified once occupied

* Nationwide House Energy Rating Scheme. ** Equipment Energy Efficiency program. *** Water Efficiency Labelling and Standards scheme.

As shown, the EVK development incorporates multiple sustainable urbanism initiatives and innovations that address energy and water consumption levels at both a household and development scale. These initiatives and innovations have been shown to be an evolution of the approach taken at the nearby WGV.

The modelling of energy and water performance shows that ambitious targets can be met. With greenhouse gas emissions reducing in line with the energy and water performance at EVK, the project will provide a real-world, commercially viable example of a response to the need for the built environment to play an effective role in meeting the challenge of climate change and reducing the impact of human habitation on the environment. It has taken the lessons learnt from the neighbouring WGV precinct in terms of energy- and water-saving initiatives and improved upon these in the Perth context. The detailed guidelines and modelling work discussed highlight the planning that needs to go into designing and building innovative homes and precincts to further the ideas of net zero energy homes, WSUD, and smart cities as discussed in the literature. Commercially viable demonstration projects such as EVK highlight the genuine real-world opportunities and challenges associated with reducing greenhouse gas emissions and water use in cities around the world. Future research related to EVK will include the post-occupancy monitoring of the homes and energy and water systems when they are occupied by residents, engagement with the residents to assess their views on the liveability of the development and addressing challenges that will inevitably arise during the occupancy of the project. This will further the lessons learnt from this embedded living laboratory project to include the views of the residents in the sustainability innovations of the precinct. Further research into the topics covered will include how net zero energy homes and precincts can exist while still connected to the main energy grid system, further design innovations utilizing innovative technology and larger demonstration project examples of the technology that will create the smart and regenerative cities of the future.

Author Contributions: Conceptualization, J.B., M.M. and M.T.; methodology, J.B., M.M. and M.T.; software, J.B., M.M. and M.T.; validation, J.B., M.M. and M.T.; formal analysis, J.B., M.M. and M.T.; investigation, J.B., M.M. and M.T.; resources, J.B., M.M. and M.T.; data curation, J.B., M.M. and M.T.; writing—original draft preparation, J.B., M.M., M.T. and J.K.B.; writing—review and editing, J.B., M.M., M.T. and J.K.B.; visualization, J.B., M.M. and M.T.; supervision, J.B. and M.M.; project administration, J.B., M.M. and M.T.; funding acquisition, J.B. and M.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received funding from the Cooperative Research Centre for Low Carbon Living, an Australian Government Initiative, and the RENeW Nexus project supported by the Australian Government through the Smart Cities and Suburbs Program.

Acknowledgments: This paper has drawn on the work of DevelopmentWA and their consultants (particularly spaceagency, Josh Byrne & Associates and TABEC Consulting Engineers) commissioned as part of the design and development of the project. The authors also acknowledge the work undertaken by the ReNew Nexus Smart City project involving Curtin University, Power Ledger, City of Fremantle, Cisco, CSIRO/Data 61, Murdoch University, Synergy, Western Power, Water Corporation and the Australian Energy Market Operator.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. United Nations Global Indicator Framework for the Sustainable Development Goals and Targets of the 2030 Agenda for Sustainable Development. Available online: https://unstats.un.org/sdgs/indicators/indicators-list/ (accessed on 6 July 2020).
2. IPCC. *Climate Change 2014 Mitigation of Climate Change Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Edenhofer, O., Sokona, Y., Minx, J.C., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Kriemann, B., et al., Eds.; Cambridge University Press: Cambridge, MA, USA; New York, NY, USA, 2014; ISBN 9781107654815.
3. Newton, P.W.; Rogers, B.C. Transforming built environments: Towards carbon neutral and blue-green cities. *Sustainability* **2020**, *12*, 4745. [CrossRef]

4. Van Der Grijp, N.; Van Der Woerd, F.; Gaiddon, B.; Hummelshøj, R.; Larsson, M.; Osunmuyiwa, O.; Rooth, R. Demonstration projects of nearly zero energy buildings: Lessons from end-user experiences in Amsterdam, Helsingborg, and Lyon. *Energy Res. Soc. Sci.* **2019**, *49*, 10–15. [CrossRef]
5. Newton, P.; Prasad, D.; Sproul, A.; White, S. *Decarbonising the Built Environment: Charting the Transition*; Palgrave Macmillan US: Singapore, Singapore, 2019; ISBN 9789811379406.
6. Rowley, S.; Ong, R.; James, A. *Perth's Infill Housing Future: Delivering Innovative and Sustainable Housing*; Curtin University: Perth, Australia, 2017.
7. Ameller, J.; Rinaudo, J.; Merly, C. The contribution of economic science to brownfield redevelopment: A review. *Integr. Environ. Assess. Manag.* **2020**, *16*, 184–196. [CrossRef] [PubMed]
8. von Wirth, T.; Fuenfschilling, L.; Frantzeskaki, N.; Coenen, L. Impacts of urban living labs on sustainability transitions: Mechanisms and strategies for systemic change through experimentation. *Eur. Plan. Stud.* **2019**, *27*, 229–257. [CrossRef]
9. Sherriff, G.; Moore, T.; Berry, S.; Ambrose, A.; Goodchild, B.; Maye-banbury, A. Coping with extremes, creating comfort: User experiences of 'low-energy' homes in Australia. *Energy Res. Soc. Sci.* **2019**, *51*, 44–54. [CrossRef]
10. Wiktorowicz, J.; Babaeff, T.; Breadsell, J.; Byrne, J.; Eggleston, J.; Newman, P. WGV: An Australian urban precinct case study to demonstrate the 1.5C agenda including multiple SDGs. *Urban Plan.* **2018**, *3*, 64–81. [CrossRef]
11. Energy transformation taskforce. In *Distributed Energy Resources Roadmap*; Government of Western Australia: Perth, Australia, 2019.
12. Wilkinson, S.; Davidson, M.; Morrison, G.M. Historical transitions of Western Australia's electricity system, 1880-2016. *Environ. Innov. Soc. Transit.* **2020**, *34*, 151–164. [CrossRef]
13. Baborska-Narozny, M.; Stevenson, F.; Ziyad, F.J. User learning and emerging practices in relation to innovative technologies: A case study of domestic photovoltaic systems in the UK. *Energy Res. Soc. Sci.* **2016**, *13*, 24–37. [CrossRef]
14. Whaley, D.; Berry, S.; Moore, T.; Sherriff, G.; O'Leary, T. Resident's issues and interactions with grid-connected photovoltaic energy system in high-performing low-energy dwellings: A user's perspective. In *Proceedings of the 10th International Conference in Sustainability of Energy and Buildings (SEB'18)*; Kaparaju, P., Howlett, R.J., Littlewood, J.R., Ekanyaka, C., Vlacic, L., Eds.; Springer: Cham, Switzerland, 2019; pp. 413–424.
15. Talari, S.; Shafie-Khah, M.; Siano, P.; Loia, V.; Tommasetti, A.; Catalão, J.P.S.; Tah, J.H.M. A review of smart cities based on the internet of things concept. *Energies* **2017**, *10*, 421. [CrossRef]
16. Han, J.; Yoon, Y.; Han, K. Urban planning and smart city decision data processing using big data analytics. *Sensors* **2018**, *18*, 2994.
17. Alam, M.; Porras, J. Architecting and designing sustainable smart city services in a living lab environment. *Technologies* **2018**, *6*, 99. [CrossRef]
18. Tjandraatmadja, G. The role of policy and regulation in WSUD implementation. In *Approaches to Water Sensitive Urban Design: Potential, Design, Ecological Health, Urban Greening, Economics, Policies and Community Perceptions*; Sharma, A.K., Gardner, T., Begbie, D., Eds.; Elsevier: Amsterdam, The Netherlands, 2019; pp. 87–117.
19. Mouritz, M.J. *Sustainable Urban Water Systems: Policy and Professional Praxis*; Murdoch University: Murdoch, Australia, 1996.
20. Sharma, A.K.; Gardner, T.; Begbie, D. (Eds.) *Approaches to Water Sensitive Urban Design: Potential, design, Ecological Health, Urban Greening, Economics, Policies, and Community Perceptions*; Elsevier: Amsterdam, The Netherlands, 2018.
21. Byrne, J.; Green, M.; Dallas, S. WSUD implementation in a precinct residential development: Perth case study. In *Approaches to Water Sensitive Urban Design: Potential, Design, Ecological Health, Urban Greening, Economics, Policies and Community Perceptions*; Sharma, A.K., Gardner, T., Begbie, D., Eds.; Elsevier: Amsterdam, The Netherlands, 2018; pp. 541–559.
22. McFarlane, D. Will perth have enough water for its diverse needs in a drying climate? In *Planning Boomtown and Beyond*; Beirmann, S., Olaru, D., Paul, V., Eds.; UWA Press: Perth, Australia, 2016; pp. 209–237.
23. Rogers, B.; Hammer, K. Realising the Vision of a Water Sensitive City. Available online: https://www.thesourcemagazine.org/realising-the-vision-of-a-water-sensitive-city/ (accessed on 7 July 2020).

24. Liedtke, C.; Baedeker, C.; Hasselkuß, M.; Rohn, H.; Grinewitschus, V. User-integrated innovation in Sustainable Living Labs: An experimental infrastructure for researching and developing sustainable product service systems. *J. Clean. Prod.* **2015**, *97*, 106–116. [CrossRef]
25. Chronéer, D.; Ståhlbröst, A.; Habibipour, A. Urban living labs: Towards an integrated understanding of their key components. *Technol. Innov. Manag. Rev.* **2019**, *9*, 50–62. [CrossRef]
26. Burbridge, M.; Morrison, G.M.; van Rijin, M.; Silverster, S.; Keyson, D.V.; Virdee, L.; Baedeker, C.; Liedtke, C. Business models for sustainability in living labs. In *Living Labs Design and Assessment of Sustainable Living*; Keyson, D.V., Guerra-Santin, O., Lockton, D., Eds.; Springer International Publishing: Cham, Switzerland, 2017; pp. 391–403.
27. Leminen, S.; Westerlund, M. Towards innovation in living labs networks. *Int. J. Prod. Dev.* **2012**, *17*, 43–59. [CrossRef]
28. Zou, P.X.W.; Xu, X.; Sanjayan, J.; Wang, J. Review of 10 years research on building energy performance gap: Life-cycle and stakeholder perspectives. *Energy Build.* **2018**, *178*, 165. [CrossRef]
29. Gram-Hanssen, K.; Georg, S.; Christiansen, E.; Heiselberg, P. What next for energy-related building regulations? The occupancy phase. *Build. Res. Inf.* **2018**, *46*, 790–803. [CrossRef]
30. *Closing the Gap between Design & As-Built Performance Evidence Review*; Zero Carbon Hub: London, UK, 2014.
31. Berry, S.; Davidson, K.; Saman, W. The impact of niche green developments in transforming the building sector: The case study of Lochiel Park. *Energy Policy* **2013**, *62*, 646–655. [CrossRef]
32. Breadsell, J.; Morrison, G.M.; Byrne, J. Pre- and post-occupancy evaluation of resident motivations for and experiences of establishing a home in a low-carbon development. *Sustainability* **2019**, *11*, 3970. [CrossRef]
33. Byrne, J.; Law, A.; Hosking, R.; Breadsell, J.; Syed, M.; Babaeff, T.; Morrison, G.; Newman, P. *Mainstreaming Low Carbon Residential Precincts: The WGV Living Laboratory*; CRC for Low Carbon Living: Sydney, Australia, 2019.
34. LandCorp Innovation through Demonstration: WGV. Available online: https://www.landcorp.com.au/innovation/wgv/ (accessed on 21 May 2020).
35. Roggema, R. The future of sustainable urbanism: A redefinition. *City Territ. Archit.* **2016**, *3*, 22. [CrossRef]
36. Breadsell, J.K.; Byrne, J.J.; Morrison, G.M. Household energy and water practices change post-occupancy in an Australian low-carbon development. *Sustainability* **2019**, *11*, 5559. [CrossRef]
37. Bioregional East Village on Knutsford–Creating a Better Model of Housing for Australia. Available online: https://www.bioregional.com/bioregional-australia/bioregional-australia-our-work/east-village-knutsford-creating-a-better-model-of-housing-for-australia (accessed on 9 May 2020).
38. DevelopmentWA Innovation through Demonstration. Available online: https://developmentwa.com.au/itd (accessed on 9 May 2020).
39. Green, J.; Newman, P. Planning and governance for decentralised energy assets in medium-density housing: The WGV gen Y case study. *Urban Policy Res.* **2017**, *1146*, 201–214. [CrossRef]
40. Breadsell, J.; Morrison, G.M. Changes to household practices pre- and post-occupancy in an Australian low-carbon development. *Sustain. Prod. Consum.* **2020**, *22*, 147–161. [CrossRef]
41. Green, J.; Morrison, G. *Citizen Utilities: Unlocking Australian Strata Development to the Benefits of Solar and Battery Storage Innovations: A Report for the Australian Renewable Energy Agency*; Curtin University: Perth, Australia, 2018.
42. Hansen, P.; Morrison, G.M.; Zaman, A.; Liu, X. Smart technology needs smarter management: Disentangling the dynamics of digitalism in the governance of shared solar energy in Australia. *Energy Res. Soc. Sci.* **2020**, *60*, 101322. [CrossRef]
43. Landgate Survey or Strata Plans. Available online: https://www0.landgate.wa.gov.au/titles-and-surveys/survey-or-strata-plans (accessed on 30 May 2020).
44. Pacifici, C. *Greening Strata Title Schemes in Western Australia Greening Strata Title Schemes in WA: Turning Barriers into Opportunities for Individual Owners to Implement Environmentally Sustainable Provisions in Existing Residential Strata Dwellings*; Curtin University Sustainability Policy (CUSP) Institute: Perth, Australia, 2011.
45. Knutsford Knutsford. Available online: https://www.knutsford.com.au/ (accessed on 21 May 2020).
46. Department of Industry, Science, Energy and Resources. Nationwide House Energy Rating Scheme (NatHERS). Available online: https://www.nathers.gov.au/ (accessed on 28 April 2020).
47. Power Ledger Power Ledger Reveals Australian Government Smart Cities Project for 100% Renewable Energy. Available online: https://www.powerledger.io/article/power-ledger-reveals-australian-government-smart-cities-project-for-100-renewable-energy/ (accessed on 28 April 2020).

48. Wilkinson, S.; Hojckova, K.; Eon, C.; Morrison, G.M.; Sandén, B. Is peer-to-peer electricity trading empowering users? Evidence on motivations and roles in a prosumer business model trial in Australia. *Energy Res. Soc. Sci.* **2020**, *66*, 101500. [CrossRef]
49. Enker, R.A.; Morrison, G.M. The potential contribution of building codes to climate change response policies for the built environment. *Energy Effic.* **2020**, *13*, 789–807. [CrossRef]
50. Hunt, J.; Anda, M.; Ho, G. Water balance modelling of alternate water sources at the household scale. *Water Sci. Technol.* **2011**, *63*, 1873–1879. [CrossRef] [PubMed]
51. *Perth Residential Water Use Study 2008/2009*; Water Corporation: Perth, Australia, 2010.
52. *Urban Forest Plan*; City of Fremantle: Fremantle, Australia, 2017.
53. Kinesis CCAP Precinct (PRECINX). Available online: https://kinesis.org/ccap-precinct (accessed on 14 July 2020).
54. Mouritz, M. *East Village: A Sustainable Urbanism Project by LandCorp*; CRC for Low Carbon Living: Sydney, Australia, 2019.
55. *Lot 1819 Energy Strategy: Review of Energy Options and Outcomes*; Josh Byrne & Associates: Fremantle, Australia, 2018.
56. *Urban Water Management Plan for Lot 1819 Blinco St, Fremantle*; Josh Byrne & Associates: Fremantle, Australia, 2018.
57. Breadsell, J.K.; Eon, C.; Morrison, G.M. Understanding resource consumption in the home, community and society through behaviour and social practice theories. *Sustainability* **2019**, *11*, 6513. [CrossRef]
58. Torriti, J. Understanding the timing of energy demand through time use data: Time of the day dependence of social practices and energy demand. *Energy Res. Soc. Sci.* **2017**, *25*, 37–47. [CrossRef]
59. Power Ledger Project Update: Fremantle Smart City Development. Available online: https://medium.com/power-ledger/project-update-fremantle-smart-city-development-b16ccce2eb8f (accessed on 9 June 2020).
60. Power Ledger Power Ledger. Available online: https://www.powerledger.io/ (accessed on 9 May 2020).
61. Breadsell, J.K.; Eon, C.; Byrne, J.; Morrison, G.M. *Addressing the Discrepancy between as-Built and as-Designed in Australian Energy Efficient Buildings*; IPEEC Building Energy Efficiency Task Group: Sydeny, Australia, 2020.
62. Fabi, V.; Spigliantini, G.; Corgnati, S.P. Insights on smart home concept and occupants' interaction with building controls. In *Proceedings of the Energy Procedia*; Elsevier: Amsterdam, The Netherlands, 2017; Volume 111, pp. 759–769.
63. Paskaleva, K.; Evans, J.; Martin, C.; Linjordet, T.; Yang, D.; Karvonen, A. Data governance in the sustainable smart city. *Informatics* **2017**, *4*, 41. [CrossRef]