RETROFITTING CITIES

CHALLENGES AND OPPORTUNITIES IN AUSTRALIA

ISSUES PAPER

THE RETROFIT LAB

THE UNIVERSITY OF MELBOURNE

Melbourne Centre for Cities

RETROFITTING CITIES

CHALLENGES AND OPPORTUNITIES IN AUSTRALIA

ISSUES PAPER

The Retrofit Lab acknowledges the Traditional Owners of the Country this paper was written on, the Wurundjeri and Bunurong peoples of the Kulin Nation, the true custodians and pays respect to elders past, present and emerging.

Contents

Authors:

Prof. Sarah Bell City of Melbourne Chair in Urban Resilience and Innovation, Melbourne Centre for Cities, The University of Melbourne

Dr. Judy Bush Senior Lecturer in Urban Planning, Architecture, Building and Planning, The University of Melbourne

Enzo Lara-Hamilton Research Assistant, Melbourne Centre for Cities, The University of Melbourne

--

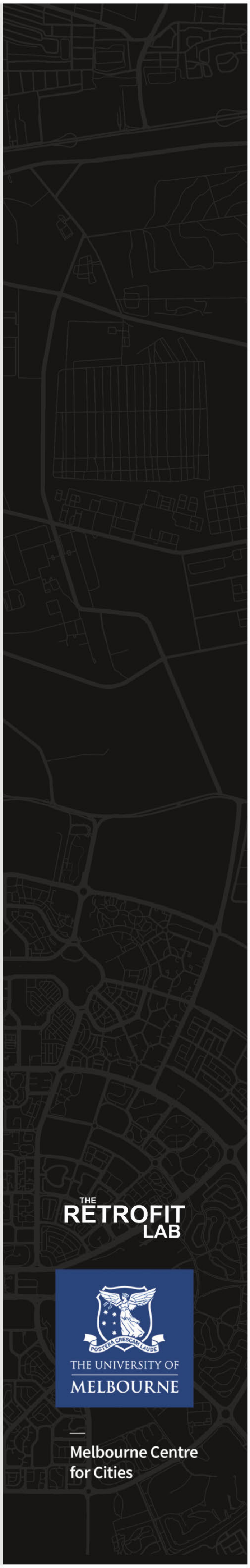
This research report has been developed by the Melbourne Centre for Cities at the University of Melbourne. It is intended to inform research, policy and public discussions on the present and future of cities. The authors have sought to ensure the accuracy of the material in this document, but they, the Centre and the University of Melbourne will not be liable for any loss or damage incurred through the use of this report.

Published by the University of Melbourne, 2023

To cite this report: Bell, S., Bush, J. and Lara-Hamilton, E. (2023) 'Retrofitting Cities: Challenges and Opportunities in Australia, Issues Paper'. *Melbourne Centre for Cities.*

This report is under a Creative Commons license (Attribution-Non-Commercial 4.0 International).

Cover image: *Marita Doak and Adrian Barboiu via Pexels*



INTRODUCTION

Retrofitting is the process of upgrading existing physical systems to improve their performance (Eames et al. 2014, Sayce et al. 2022, Wilkinson 2011). It is an approach that can future-proof Australian cities, improving the buildings, infrastructure, and landscapes that already exist. Retrofitting can be employed across many sectors, at many scales; from energy efficient light upgrades in a suburban dwelling to precinct-wide energy, water and waste system improvements (Drosou et al. 2018). This paper outlines a comprehensive, systems approach to retrofitting, stressing that integrated urban retrofits can provide effective development of sustainable and resilient cities. This is increasingly important for the range of global environmental issues that are rapidly changing the way cities function. In adopting retrofit, cities can simultaneously reduce embodied and operational emissions, resource consumption, and waste, whilst adapting to new requirements that the future communities of Australia need.

Changing Australia's approach toward buildings, infrastructure, and landscape development is urgent. The UNFCCC describes climate change, pollution, and biodiversity loss as the triple planetary crisis. Australia's actions will determine how resilient it will become as these environmental crises develop.

Australia's existing buildings are made of an estimated 3.8 billion tonnes of material, which emitted 1804 million tonnes of CO_2e, consumed 24,218 terajoules of energy and used 31.5 million m^3 of water when created. Projections to 2060 indicate Australia will require almost twice this amount to replace buildings that reach the end of their life (Soonsawad et al. 2022). Another projection indicates if Australia continues at the current rate of constructing new detached dwellings, by 2050 the life cycle emissions they emit will accumulate to to 3.6 billion tonnes of CO2e, greatly exceeding Australia's climate commitments (Schmidt et al. 2020).

These projected requirements are echoed across the world, despite insufficient global resources or carbon allocation to account for such demands (International Resource Panel 2018). Australia requires a shift away from the linear model of demolition, landfill, and new construction toward retaining, improving and extending the life of existing buildings according to circular economy principles.

Urban retrofit can shift business as usual practices toward resilience and circularity, helping to achieve Australia's updated goal of 43% greenhouse gas emissions reduction from 2005 levels (Commonwealth of Australia 2022). Reducing the fifth of Australia's yearly emissions that buildings contribute or the 70% of yearly emissions that infrastructure enables will require significantly different mindsets, prioritising reuse and retrofit over rebuild (Climate works 2018; Climate works 2022).

The most recent 2022 IPCC Mitigation Report stresses *'established cities will achieve the largest GHG (greenhouse gas) emissions savings by replacing, repurposing, or retrofitting the building stock, strategic infilling and densifying, as well as through modal shift and the electrification of the urban energy system.'*

Retrofitting Australian buildings, infrastructure, and landscapes can increase resilience to the shocks and stresses cities continue to face, drastically reduce emissions and resource consumption, while also providing numerous other environmental, health, and economic benefits to urban communities (Eames et al. 2014). This Issues Paper addresses Australian cities, their buildings, infrastructure, and landscapes, highlighting challenges and opportunities for larger retrofiting at the scale required to meet current targets and future needs.

IMAGE OF HIGH-RISE BUILDINGS IN MELBOURNE CBD. IMAGE BY DANIEL CLARK VIA PEXELS

URBAN RETROFIT: BUILDING, INFRASTRUCTURE, AND LANDSCAPE SYSTEMS

The practice of retrofitting implies a broad set of methods which are performed differently in different contexts. Refurbishment, renovation, adaptive reuse, repair and restoration are adjacent terms that are used in similar ways to describe alterations to pre-existing systems.

To develop effective resilience to the global issues that cities now face, retrofitting must deal with the interrelated physical systems of buildings, infrastructure, and landscapes, comprehensively, at the precinct and city scale. This is understood as urban retrofit (Eames et al. 2014). Each of these systems have varied stakeholders, human and non-human, which require different retrofitting practices. They are also interconnected and complex, meaning retrofit opportunities lie not only in each isolated system, but also in the connections between them. Building, infrastructure, and landscape systems each differ in requirements, skills, business types, policies, and innovations, and are distinguished as different disciplines, but they are nevertheless interconnected.

In all three cases, retrofitting provides possibilities for the mitigation and adaptation of climate change, increase biodiversity and create healthy cities. Combining these systems through bio-integration, the integration of natural elements and systems into existing inorganic-built environments, can restore and drastically improve depleted ecosystems at the city scale (Hyde et al. 2012). Region-sensitive retrofitting of green infrastructure to existing urban systems creates such possibilities. Whole street green wall and green roof retrofitting can provide a primary benefit of reduced energy requirements and shading to buildings, and secondary benefits by reducing urban heat-island effect to streets, health improvements and increased biodiversity for the human and non-human communities that use them, which is crucial for urban resilience (RICS 2016). Approaching projects in isolation often results in missed opportunities outside the property boundary, when broader collaboration for climate mitigation and ecological rehabilitation are needed more than ever.

The reasons and benefits for retrofitting are abundant. Modifications for energy efficiency and thermal comfort that pay for themselves through operational cost savings is a common reason to retrofit buildings. Decisions to perform infrastructure retrofits and landscape improvements vary depending on project scope. Other reasons may include:

- mitigating urban heat island effect,
- changing accessibility or aged care needs,
- adapting to and mitigating climate change,
- increasing green jobs,
- shifting to a bike friendly city,
- home improvement,
- lowering bills,
- diversifying flora,
- creating resilient habitats for fauna,
- electrifying buildings,
- applying ESG in the commercial property sector,
- increasing rent yield and higher paying tenants,
- increasing the lifespan and functionality of a project,
- maintaining local communities.

A single retrofit project can provide multiple economic, environmental, and social benefits which can be more effective at the scale of an urban retrofit. Many other reasons and benefits for retrofitting are expanded on in the subsequent section.

Retrofitting approaches vary dependent on the project type, but all effective retrofits begin with an initial baseline assessment (Ma et al. 2012). This assessment provides verification of the effectiveness of any alteration to a building, infrastructure, or landscape asset. Baseline assessments document any relevant information about an existing asset, depending on what will be upgraded and why. The following section outlines current building, infrastructure and landscape practices of retrofit, assuming all projects perform an initial baseline assessment to measure their improvements.

RETROFITTING BUILDINGS

Building retrofitting is the improvement and reuse of pre-existing structures and elements (Che Husin et al. 2019). Carl Elefante, ex-President of the American Institute of Architects, states ‘the greenest building is…one that is already built’ (Elefante 2012). Elefante highlights the shift toward new *green* construction in the United States, which, while a step towards more sustainable cities, does not address the ‘overwhelming vastness of the existing building stock’ (Elefante 2012). In the context of the climate, biodiversity, and health crises, improving what already exists through sustainable retrofitting is crucial for future populations in Australian cities and the planet (Prasad et al. 2021). The embodied materials of the existing Australian building stock have already greatly impacted the environment. If Australia continues business as usual, by 2060 it may require as much as twice the materials currently used in Australia's buildings (Soonsawad et al. 2022).

Distinguishing between Deep and Light retrofits is useful in capturing degrees of disruption from a building upgrade. The UK Green Building Council uses these categories in its current Net Zero Retrofits (2022) guide which presents these classifications and their subsequent trade-offs (UKGBC 2022). Deep retrofits provide large savings for operational systems but disrupt building operations. Major refurbishments, and some adaptive reuse projects can also be considered deep retrofits.

AERIAL VIEW OF MELBOURNE CBD. IMAGE BY PAT WHELEN VIA PEXELS

Such deep retrofits require larger upfront costs and disrupted tenancies but result in large long-term savings and benefits. A Deep Energy Retrofit (DER) can be any building works that reduce fossil fuel usage by at least 50% from a pre-renovation baseline, but usually requires significant disruptions when changing glazing units, facade elements and insulation types (UKGBC 2022, Zhivov and Lohse 2020). Such energy upgrades commonly correspond to improvements in indoor environmental quality, productivity and thermal comfort. These benefits must offset the lost rental income from disruptions for building owners to considered it a viable choice.

In contrast, Light retrofits can be as small as changing to energy efficient light bulbs, radiators, fan coil units or installing a new Building Management System (BMS) for greater control of operations. There is often little to no occupant disruption and are small short-term investment options with short payback periods, though they often require follow-up improvements, and can miss opportunities for greater benefits.

Retro commissioning is an adjacent light retrofit concept. It is distinguished by focusing on pre-existing technological systems of a building. Rather than construction work, commissioning is the tuning, adjusting, and calibrating of a building system for optimal operation. This may include refining BMS settings, resetting control sequences, or reducing equipment over usage. An American study of 224 office buildings indicated a median payback period of 8.5 months, a return on investment in under a year from simply retro-commissioning (Mills et al. 2005).

Deep and light retrofits are most effective when considered from an integrated systems perspective. Building systems can be interconnected, leveraging savings at several points in the retrofit process (Zhivov and Lohse 2020). Approaching retrofit with a systems perspective can provide significant emissions reductions and capital cost reductions to building owners. The Australian Sustainable Built Environment Council recommends 'project-based methodologies that reward deeper retrofits' over specific product replacements are more effective in the long term (ASBEC 2016). For example, upgrading to energy-efficient light bulbs with sensors and a green facade of an office building can be simultaneously integrated with a radiant cooling system. Together, these modifications drastically lower energy requirements and operational carbon, increase biodiversity and thermal comfort simultaneously, which would not be achieved through solely replacing light bulbs (Olgyay et al. 2010).

RETROFITTING INFRASTRUCTURE:

Retrofitting infrastructure is the upgrading of existing transport, energy, communications, water, and waste systems. Infrastructure assets are understood under these categories (Climateworks 2020):

Transport*roads, footpaths, cycle paths, airports, railways.*

Energy: *transmission and distribution lines, large-scale energy storage, substations*

Communications: *mobile transmission towers, internet and phone lines, data centres*

Water: *dams, water pipelines, sewers, treatment plants, stormwater drains*

Waste: *landfills, resource recovery centres*

TRAM IN MELBOURNE AUSTRALIA. IMAGE BY PAT WHELEN VIA PEXELS

Retrofitting infrastructures can also occur at many scales. Infrastructure upgrades range from greening urban fabric through additional flora, decarbonisation through local renewable power generation, creating cycle paths to reduce transport emission, changing to energy efficient streetlights, or water sensitive urban development like improving walkway water penetration. Of particular importance is the adaptation of infrastructure to the increasing frequency and intensity of extreme weather events. Increasing heatwaves, flooding, fires, coastal inundation will mean modifying existing infrastructure (Australian Academy of Science 2021). Though large-scale projects are driven from the top-down, there are also bottom-up infrastructure retrofits that are participatory and community led moving to more resilient and ethical practices (Johnson et al. 2021).

RETROFITTING LANDSCAPES:

Landscapes are biophysical systems of interconnected flora, fauna, fungal and microbial life, biogeochemical flows, water, and soils which function across many scales. Landscape retrofitting branches across concepts of ecosystems, green infrastructure, and nature-based solutions, contributing towards more resilient, low-carbon cities through a wide range of improved functions or 'ecosystem services', including cooling, stormwater management, carbon sequestration, air purification, localised food production and biodiversity habitat provision. A robust conceptual framework by the IPBES is a model of interactions between the natural world and human societies, important when considering nature and its increasing integration with cities (Oke et al. 2021):

'Nature for nature' – nature has intrinsic value, as biodiverse ecosystems which are required for life.
'Nature for society' – nature has utilitarian value, providing goods and services including climate resilience, air and water quality.
'Nature for culture' – nature has cultural value, supporting physical and mental wellbeing and social connectedness to communities.

Ecological restoration can be considered a form of landscape retrofitting, insofar as it is a process of repairing and enhancing existing landscape elements (Aronson et al. 2006). Landscape retrofit practices may include the improvement and restoration of these biophysical systems and are not necessarily financially driven. Ecosystem retrofits can provide improved services to urban environments when integrated into existing built forms. Restoring, revegetating, and improving green spaces like parks, gardens, urban forests, waterways and creating stormwater retention ponds and wetlands can all be considered retrofits to existing systems (Elmqvist et al. 2015). In addition to retaining existing lands dedicated to ecosystems and their inhabitants, integrating natural elements and landscapes into building and infrastructure projects is becoming more commonplace as ESG is adopted and is crucial for urban resilience.

ADVANTAGES AND OPPORTUNITIES OF RETROFITTING

Retrofitting buildings, infrastructure and landscapes provides multiple advantages and opportunities, including positive impacts on the climate, health, biodiversity, and significant economic benefits. The degree to which projects will create value depends on multiple factors, the level of investment and scope of retrofit are key drivers, with integrated approaches yielding more positive impacts.

Retrofitting can provide positive economic impacts through the creation of green jobs. As demonstrated by the Million Jobs Plan, an Australian low-carbon economy has the potential to provide 1,778,000 job years over 5 years. Retrofitting buildings and transport, land regeneration, and subsequent training accounts for 713,500 job years in this estimation (BZE 2020).

Residential, commercial, and industrial buildings, account for one fifth of Australia's annual greenhouse gas emissions (Yu et al. 2017, Climateworks 2020). If Australia is to reach net zero by 2050, the existing construction industry must shift toward more sustainable practices that retain existing materials and improve energy performance. Retrofitting existing buildings and upgrading building services is estimated to save a potential $17 billion and 171Mt of greenhouse gas emissions over a 15-year period (ASBEC 2016). Such financial and subsequent ecological benefits from retrofitting buildings would also provide a healthier, more resilient built environment.

Obsolescence of older buildings will also need addressing, the diminishing usefulness or performance of an asset is not always due to technological inefficiencies, but also financial impacts that modifications can help avoid such as the changing requirements of Central Business Districts after the Covid-19 pandemic (Buitelaar et al. 2021).

ASBEC estimates Australia's building sector can deliver up to 28% of Australia's 2030 emissions reduction target, whilst creating healthier, more productive cities if strategic action and policy is implemented (ASBEC 2016). Infrastructure assets further contribute 15% of total greenhouse gas emissions to Australia's annual total. These assets further enable 55% of annual emissions through activities they facilitate (Climateworks 2020). Retrofitting infrastructure presents opportunities to increase performance and extend the life of assets whilst adapting to and mitigating ecological crises. Creating such resilience in the built environment means modifying infrastructure and buildings to work better together, to deal with new social and ecological challenges. This is most effective at a precinct scale.

CLIMATE BENEFITS:

- Net zero or reduction of carbon emissions, both embodied and operational, which mitigates the climate crisis (Olgyay et al. 2010).
- Adaptation of the built environment for pandemics, flooding, fires, heatwaves and other extreme weather events (VBA 2014).
- Improving energy, waste and water management systems for efficient resource reduction, usage and circularity (Muhammad et al. 2017).
- Sequestration of carbon through increasing green infrastructure as nature-based carbon sinks. (Ariluoma et al. 2021).

HEALTH BENEFITS:

- Improving Internal Environmental Quality (IEQ) (Camacho-Montano et al. 2019).
- Urban heat island effect (UHI) mitigation through green infrastructure (Baldwin et al. 2020, Douglas et al. 2021).
- Changing the functional requirements of buildings for aging populations and people with disabilities (AHRC and MADA 2022).
- Increased thermal comfort (Eames et al. 2014).

BIODIVERSITY BENEFITS:

- Increased biodiversity through green retrofits of buildings or infrastructure that increase urban habitats for species of flora and fauna (Williams et al. 2014).
- Pollution reduction (Elmqvist et al. 2015).
- Habitat restoration and creation (Elmqvist et al. 2015).
- Urban Heat Island Effect mitigation (Baldwin et al. 2020, Douglas et al. 2021).

ECONOMIC BENEFITS:

- Providing high quality jobs (Jagger et al. 2013).
- Increasing productivity (UKGBC 2022).
- Quality of assets (Wilkinson 2013).
- Significant reduction in building and infrastructure operational costs (ASBEC and Climateworks 2016).
- Improving rental yield through increased building ratings and higher paying tenants (Wilkinson 2018).
- Less labour and material costs (Sayce et al. 2022).

OTHER BENEFITS:

- Avoiding Obsolescence e.g adapting offices to flexible working or commercial to residential conversions.
- Opportunities for improving social infrastructure such as ventilation and energy sources in schools, pools, and hospitals.
- Empowering communities and preventing displacement.
- Retaining historical buildings whilst improving environmental performance (Mazzarella 2015).
- Export potential to growing cities around the world, particularly ASEAN markets (McKinsey 2021).

KING STREET BRIDGE OVER THE YARRA RIVER. IMAGE BY: ROBERT STOKOE VIA PEXELS

CHALLENGES FOR RETROFITTING AUSTRALIAN CITIES

Key challenges facing retrofit uptake can be understood through three interrelated frameworks: Skills and Education, Policy and Business, and Research and Innovation. Main challenges of each framework are discussed below and are often consistent across buildings, infrastructure, and landscape systems. These challenges are wide ranging, and the majority of construction activity remains centered on new buildings and infrastructure. The knowledge and technology to perform effective retrofits of buildings and infrastructure already exists, but is not currently prioritised. Below are some of the important challenges that, if overcome, will refocus toward a retrofit-first mindset.

SKILLS AND EDUCATIONAL CHALLENGES

Preparing the Australian workforce with skills for retrofit requires education and training. Broadly, skills are defined as abilities and competencies of someone to undertake their required roles (Jagger et al. 2013, Bevon et al. 2020). Green and low-carbon skills like sustainable retrofitting focus on manufacturing, installing, and operating new low-carbon technologies (Infrastructure Australia 2021), with additional challenges in retrofitting building components that have been manufactured off-site. Such skills will require training across the supply chain, presenting new challenges for the workforce.

In the domain of buildings and infrastructure, skill gaps and shortages take several years for industries to 'catch up' to learn new technical skills as industries and market demands change. Emerging skills over the last five years in the construction sector have been increasing technical skills around brownfields and software across occupation groups (Infrastructure Australia 2021). Brownfields, being land previously built with varying amounts of existing development, require differing skills to empty greenfield developments. Skills such as surveying existing conditions of structures using innovative technologies make these processes easier but require new specialised technical skills (Bevon et al. 2020) which take time to learn and implement. Newer education in several countries cover these skills such as UK-accredited building surveying courses by the Royal Institution of Chartered Surveyors (RICS 2016).

Innovative technologies and processes are emerging rapidly across occupation groups and so require new skills training for widespread implementation. Project management professionals, engineers, scientists, architects, trades, sustainability consultants and labourers increasingly require specialised skills implementing technology across supply chains. As industries move to widespread implementation of innovative technologies like design and manufacturing automation, digital twins, product platforms, and NZE retrofits, obsolete skills will eventually be replaced (Infrastructure Australia 2021).

Along with technical skill challenges, general communication and data skills hinders the decision to retrofit. A lack of accessible information, resources, and training to understand the value of green building and retrofitting leads to misinformed assumptions about the effectiveness of a retrofit approach. Particularly at points of sale, without extensive knowledge of financial and other benefits , marketing approaches lack adequate understanding and communication of low-carbon upgrades, designs, and technology (Rauland et al. 2015). Additionally, retrofits understood as only a 'return on investment' rather than a triple bottom line approach undervalues the full impacts of projects. These knowledge and communication skill gaps result in poor pricing, concealing significant added value which go unnoticed by consumers. (Ma et al. 2012) It is expected that the increasing implementation of Environmental and Social Governance will lead to certification tools and awareness that will help quantify and promote retrofit.

Such communication tools already exist, and are driving demand for green projects, but remain largely focused on new developments. There are important labelling and certification schemes that exist in Australia (such as NABERS, natHERS, Green Star, Energy Efficiency appliance ratings and Infrastructure Sustainability [IS] ratings as well as internationally (LEED, ISO, GRESB, WELL) which intend to highlight the value of green projects and practices, however they require more widespread uptake and prioritisation of material retention and reuse. (Rauland et al. 2015, ASBEC and Climateworks 2017)

Stakeholders across the whole supply chain require new technical and communication coordination, training, and skills for retrofitting uptake to increase. Professional services, Suppliers, Installers, Educators, Membership bodies and Chambers of Commerce all require new skills so retrofitting can become desirable; varied types of educational programs will play a key role.

POLICY AND BUSINESS CHALLENGES

Retrofit must be economically viable to be considered successful from a business perspective, but in some cases, a portion of economic costs can be traded for social and environmental benefits (Wilkinson 2013).This is largely dependent on the stakeholders of a given retrofit project and the driving decision-making processes behind it. The main financial challenges for investment in retrofits are not having sufficient funds for the project, high upfront costs with long return-on-investments (ROI), or lower profit margins and earning potential than new builds (Alam et al. 2016). Policy incentives, new tools and business coordination are required if retrofitting is to become sustainable best practice and appealing for investors. Circular economy principles must also be implemented to avoid material intensive practices that do not consider deconstruction and reuse.

There are increasing rates of energy efficient retrofitting globally, with federal and state programs that are improving building performance, however measures are not deep enough for complete decarbonisation. To achieve building stock decarbonisation by 2050, the IPCC assumes 'deep' retrofit rates between 2.5% to 10% of a country's building stock per annum. (IPCC 2022) The current EU28 renovation rate (2019) is approximately 1%, with little variation between members (European Parliament 2016). In the City of Melbourne, 7 buildings are retrofitted per year when 77 per annum are needed to achieve net zero by 2040 (City of Melbourne 2022).

The knowledge and technology to decarbonise buildings already exists and there are also proven innovative policies and incentives to promote a low-carbon shift (Rauland et al. 2015). However, implementation of such policy and business incentives are not yet business as usual, nor is acknowledging retrofit as a frequently more sustainable option to redevelopment. ASBEC and Climateworks highlight energy efficiency has been limited to a small number of market segments. Namely, market leaders, some developers of premium and A-grade office buildings and boutique sustainability-focused developments (ASBEC and Climateworks 2017).

In the Australian building context, policy and regulations for environmental sustainability were only legislated in the BCA (now NCC) in 2006, (Wilkinson 2013) meaning a large portion of the existing building stock of Australia performs poorly on energy efficiency and other measures. In 2010, the Commercial Building Disclosure program was put in place requiring commercial buildings over 2000m2 to disclose their energy efficiency information, which was lowered to 1000m2 in 2017.

While changes like these in policy drive businesses toward retrofitting, progress in improving Australian buildings, particularly energy performance has been limited. It is estimated by 2050 that 7 million existing homes and a third of commercial buildings will not being subject to improved energy efficiency measures in the National Construction Code (Commonwealth of Australia 2019). Recent updates to the NCC are set to curb this estimate, but standards remains lower than required to achieve net zero and embodied carbon is unenforced. ASBEC estimates improvements of only a combined 7% in energy intensity were observed across commercial and residential building stock from 2010-2017 (ASBEC and Climateworks 2017).

The 'vicious circle of blame' around green projects prevent uptake of green building practices, as stakeholders blame others for continuing business-as-usual, often leading to lower profit margins for stakeholders that do go ahead with retrofit projects (Rauland et al. 2015). Constructors claim developers don't commission environmentally conscious approaches to building. Developers claim investors don't require them. Investors claim users don't demand them. Users do not demand them because they claim they are not offered to them (Sedlacek and Maier 2012). This perpetuates existing, environmentally intensive building practices and reluctance to retrofit. It is also tied to the challenges of competing requirements and lack of collaboration when retrofitting.

IMAGE OF MELBOURNE SKYLINE. IMAGE BY PAT WHELEN VIA PEXELS

Low carbon or carbon-neutral upgrades require numerous stakeholders with significant collaboration and alignment if the retrofits are to be successful (Rauland et al. 2015). Collaborative difficulties arise due to competing requirements known commonly as split incentives. Building owners looking to retrofit tenanted buildings are often reluctant to improve energy efficiency or other environmental upgrades because they are not the ones who see immediate benefits. For example, Australian rental property upgrades that lower energy, water, or gas bills benefit tenants, but are paid for by landlords who do not see financial benefits (Lang et al. 2022). Conversely, renters (making up 30.6% of Australia's dwellings)(ABS 2021) are unlikely to pay for improvements to a building they do not own. These challenges are currently being addressed through strategic policy in Victoria by the Victorian Energy Upgrades program. Introduced as an extension to the Victorian Energy Efficiency Target Act in 2007, 2018 saw the creation of state-wide rebates on energy efficient products for homes and businesses, incentivising building owners to upgrade.

Occupancy barriers also prove challenging for retrofit uptake. As discussed along with a deep retrofit approach, large savings and benefits come at the cost of losing tenancy while the retrofitting is taking place. In the case of buildings, owners and tenants are reluctant to relocate, perceiving short-term financial losses (Drosou et al. 2018) over long-term savings. This may occur during a deep retrofit or even smaller upgrades to a bathroom or kitchen where occupants' activities are disrupted. One solution to this issue is the use of prefabrication, the Energiesprong program has achieved net zero housing retrofits in as little as ten days (See Case Studies).

Large building projects, infrastructure projects, and green infrastructure often have long lifespans that, if not developed correctly or retrofitted, lead to stranded assets and lock-ins (Climateworks 2020). An asset is stranded when capital expenditure does not yield expected returns due to changes in use, environment, or decarbonisation. Coal and gas power plants, coal mines and other energy infrastructure are most at risk of becoming stranded by the low carbon transition. Furthermore, large infrastructure projects such as these require large capital investments, with many stakeholders, and generally operate for 50-100 years. Developing such projects lock in patterns of infrastructure making retrofitting both buildings and surrounding infrastructure difficult and more costly when they become stranded (Climateworks 2020).

Difficulty in confirming assessment effectiveness of sustainable upgrades leads to a lack of credibility. Australian rating systems are important in driving demand for sustainable retrofits. Differences in the methods they use make comparisons and verification between projects challenging environmental retrofitting and construction, particularly carbon accounting (Mirabella and Allacker 2021). Environmentally sustainable design(ESD) ratings also require scrutiny. Nature Based Cities not-for-profit research group which states 8 ESD Rating tools do not have mandatory vegetation, retention or nature-based landscaping (ARK Resources 2022). This results in the possibility of achieving a high sustainability ratings without having any landscaped area. Whole Life-cycle Carbon (WLC) calculations, considering both embodied and operational impacts of a project, are not widely reported or enforced, concealing points of large carbon emitting. Most policies and regulations in Australia's construction sector centers around reducing operational emissions from buildings and infrastructure, however more attention is required toward the embodied emissions of the whole sector across the supply chain, as these can take between 10% and 97% of the whole life-cycle carbon emissions (Yu et al. 2017). This often perpetuates demolition and rebuilding of projects, despite high upfront greenhouse gas emissions of construction as they are not accounted for.

RESEARCH AND INNOVATION CHALLENGES

The Australian construction sector, with growing implementation of digital 4.0 technologies, is providing more efficiencies for retrofitting buildings and infrastructure. Despite these efficiencies and opportunities for retrofitting practices, innovation remains largely focused on new construction.

Construction companies are already performing low-carbon retrofits integrating 3D scanning, AI supply chain optimisation and Digital Twins (real time virtual representations of an objects or systems) to survey and digitise existing structural elements, design and build (ARUP 2019) as well as calculating embodied carbon using digital platforms. As innovative technologies and products like these develop and mature, retrofitting will shift toward adaptable, prefabricated, and repeatable processes for complex in situ challenges, as is the case with Energiesprong. Aggregate projects such as these which retrofit multiple buildings can more easily achieve economies of scale.

Innovation in retrofitting is hindered by the costs faced by first movers of new practices. The creation of innovative practices and products creates economical and logistical disadvantages, often requiring innovators to 'jump through regulatory hoops' to get approvals and delaying other processes (Rauland et al. 2015). Only after they have taken the fall, can other followers benefit and decrease innovative technology costs. This is further hindered by a lack of data sharing between projects and stakeholders. Regulatory sandpits for testing, regulatory frameworks, exemptions, and fast-tracking approval processes can overcome this issue if strategically implemented. Integrating several sectors is another challenge within retrofit projects. 'Sectoral Silos' often cause further expenses and less innovation. This can be between stakeholders of retrofit projects between industry and researchers at universities, between planning and production teams and sometimes between operational staff and planning staff (Liu 2014). Poor communication between parties also often leads to inefficiencies and missed opportunities (Rauland et al. 2015).

The energy performance gap, the disparity found between predicted energy consumption in the design stage of buildings and their actual operational energy use after construction. (SBEnrc 2019). Providing evidence of a successful retrofit requires a comprehensive baseline analysis and comparative assessment after the retrofit has taken place.

CONCLUSION

Retrofitting, as a practice of improving what already exists rather than demolishing and starting anew, can provide countless benefits to Australian cities. These benefits are not solely financial, they make cities more sustainable, resilient, climate conscious, circular, healthy, and biodiverse. They are needed more than ever, as global climate, biodiversity, and pollution emergencies continue to shock Australia's systems. Australia is continually modifying buildings, infrastructure, and landscapes as city requirements change, today's requirements call for retrofitting, toward a resilient future.

Retrofitting's challenges in domains of skills and education, policy and business, and research and innovation need to be addressed if Australia is to make retrofitting effective and common practice. An urban retrofit approach that is integrated and systematic is required to bring the greatest benefit to Australian cities. Retrofitting cities means a commitment to ecological responsibility, a sustainable economy, and the future human and non-human communities of this continent.

IMAGE OF MELBOURNE. IMAGE BY FINN WHELEN VIA PEXELS

CASE STUDIES

The following case studies are divided into two types, aggregate retrofit programs that facilitate many retrofits driving policy and incentives, and singular exemplar retrofit projects often a building, or piece of infrastructure.

ENERGIESPRONG NET ZERO RETROFIT IN NOTTINGHAM, UK, 2019 - ENERGIESPRONG INTERNATIONAL, VIA FLICKR

HAMMARBY SJÖSTAD, STADSPARTERREN, SWEDEN - HANS KLYBERG, VIA WIKICOMMONS

AGGREGATE RETROFIT PROGRAMS

THE NETHERLANDS' ENERGIESPRONG INITIATIVE

Overview: Launched in 2013, The Energiesprong is a market-led initiative for retrofitting homes to net zero energy using prefabricated elements and innovative technologies. Prefabrication allows for these retrofits to be installed in an average of under 2 weeks. Typically, a retrofit through the Energiesprong model uses insulated facades and modules integrated with renewable heat sources and PV panels.

Dates of Retrofit Program: 2013 - Ongoing

Objectives: Energiesprong retrofits emphasise aesthetics, health and comfort which in turn improves property value, and optimise designs for repeatable manufacturing and installation of specific building typologies.

Main Benefits: Net Zero Carbon over a 30-year period (with a set allowance of hot water and electricity consumption) Carbon reduction through energy efficient whole house upgrades, innovative business and policy model. Average energy use reductions of 150 kWh/m2 and 70% reduction in total energy consumption (20,000kWh to just over 6,000kWh). Speed of retrofit that avoids occupancy difficulties and provides benefits rapidly for tenants.

Shortcomings: The project still requires public subsidies, meaning the cost of retrofits per unit is not low enough to be financially self-sustaining. It is estimated that 40,000 EUR per retrofit would mean the business model could sustain itself in a privatised context.

SWEDEN'S HAMMARBY SJÖSTAD PRECINCT

Overview: Hammarby Sjöstad translated as *Hammerby Lake City,* located in Sweden is a sustainable precinct located in Stockholm's inner city on the shores of Lake Hammarby Sjo. It was originally intended to be the Olympic Village for the 2004 Olympics but became a regeneration project after losing the bid to Athens. The precinct comprises 12 sub-neighbourhoods across 200-hectares, residential and commercial areas, and open green spaces commended for it's integrated systematic approach to urban retrofit/renewal.

Dates of Retrofit: 2004 - Ongoing

Objectives: The goal of Hammarby Sjöstad is to create a sustainable precinct. Aim is for 80% of residents to commute to work using public transport, walking, or biking. The Hammarby Model, inspired by the Bo01 project in Malmö, was developed to achieve effective precinct scale sustainability. It includes features like a centralised waste management system, 100% renewable energy generation, and a storm water remediation system.

Main Benefits: Hammarby Sjöstad prioritises urban green areas, including parks, green corridors, and nature reserves. It also protects valuable natural areas and compensates for development by creating biotopes. The project promotes urban biodiversity conservation and features eco-friendly infrastructure like planted viaducts and green roofs. Pedestrian-friendly green corridors and accessible public transportation options encourage low-carbon transport. The transformation of Hammarby Sjöstad led to a quick rise in property values, which has been criticised for social exclusion and unaffordability.

THE SCHUYLKILL RIVER LOOKING SOUTH TOWARD THE PHILADELPHIA SKYLINE
BY ED YAKOVICH, VIA FLICKER

PHILADELPHIA’S STORMWATER GRANTS PROGRAM

Overview: An exemplary case presenting benefits of infrastructure retrofitting is Philadelphia Water Department’s competitive grant program: The program, initiated in July 2014 as Greened Acres Retrofit Program (GARP, provided incentives for the development of green infrastructure on private property. Government subsidies provide finance for rain gardens, green roofs, trees, and porous pavements retrofits.. Stormwater Grants Program encourages contractors and design/construction firms to bundle green infrastructure projects and compete for limited public grant funding, thereby incentivising lowest-cost retrofits on private land. Currently, the initiative provides $15 Million in funding each year for accepted proposals. Importantly, property owners are required to agree to a 45-year Operations and Maintenance agreement with the Philadelphia Water Department to certify retrofits are maintained to fulfill regulatory requirements.

The program provided improved property values for owners, reduced storm water fees, local green infrastructure maintenance opportunities for contractors, and reduction in flooding and water pollution. In part, this initiative responded to the estimated 10 trillion gallons per year of polluted flows into local waterways.

Dates of Retrofit Program: 2014 - Ongoing
Objectives: Stormwater management to reduce flooding in Philadelphia and increased biodiversity and green infrastructure.
Costing: $90,000 maximum per acre. $15 Million dedicated per year.
Main Benefits: Shared prosperity for surrounding land. Reduced flooding, increased biodiversity and competitive financing between government and landowners. Reduced property damage, reduced monthly stormwater charges, and increased marketability of assets are also incentives for investment.

THE YARRA RIVER LOOKING NORTH TOWARD MELBOURNE CBD
BY FELIX HAUMANN, VIA PEXELS

MELBOURNE’S 1200 BUILDINGS PROGRAM

Overview: The 1200 Buildings Program attempted to retrofit two thirds of Melbourne’s existing building stock. Retrofits ranged from energy efficient and indoor air quality technologies to waste and water management upgrades. Retrofitting two thirds of the municipality’s commercial stock would eliminate 383,000 tonnes of greenhouse gas emissions each year. It was further estimated $2 billion-dollar economic uplift and 8000 green jobs would be created. From 2010 to 2015, 541 buildings were retrofitted under the program.

Several policy drivers helped the process of retrofitting in Melbourne. Competitive financing of retrofit projects through the Sustainable Melbourne Fund and Environmental Upgrade Agreements both influenced building owners' actions. The government did not specify or recommend companies to perform these retrofits, this was organised by the building owner.

Dates of Retrofit Program: 2010 – 2015 (last survey)
Objectives: To retrofit 2/3 of the existing office buildings in Melbourne city (1200 buildings of 2,256) for energy efficiency.
Costing: EUA- Environmental Upgrades Agreement, a financing mechanism that allows building owners to pass retrofit costs onto next owners if sold as well as paying off using lower electricity bills.
Rating System: NABERS
Main Benefits: Lower energy bills, affordable improvements, staff productivity increases, lower greenhouse gas emissions.

RETROFIT PROJECTS

QUAY QUARTER TOWER IN 2023 AND 2014, SYDNEY - KGBO AND JASON TONG

QUAY QUARTER TOWER, SYDNEY

Overview: The Quay Quarter Tower in Sydney was created using 98 percent of the original structural walls and core of the existing building, retaining approximately 12,000 tonnes of embodied carbon. It is a multi-functional building offering work, retail and social spaces. It integrated building services with comprehensive reuse of existing riser shafts, using a range of smart building technology and facade design elements to reduce energy consumption.

Date of Initial Construction: 1976

Date of Retrofit: 2022

Rating System: 5.5 Star NABERS Office Base Energy Rating, 4 Star Base Water Rating, WELL Platinum certification, 6 Star Green Star Office Design.

Main Benefits: Emissions reduction to meet climate emergency requirements attending to embodied and operational carbon. healthy working environments, efficient energy management using smart building technology.

THE AUSTRALIAN CONSERVATION FOUNDATION'S 60L GREEN BUILDING, CARLTON, MELBOURNE - ELEKHH

THE 60L BUILDING, VICTORIA

Overview: The 60L Building, retrofitted in 2002, was a front runner in sustainable retrofitting. The undertaking of the commercial retrofit took a 'wholistic environmental approach.' It considered sustainable measures for materials, design, HVAC, Water, Energy and People whilst maintaining commercial viability.

Date of Initial Construction: 1877

Date of Retrofit: 2002

Objectives: Use of sustainable materials with low embodied carbon, integrated design of building systems, HVAC upgrades, Water management upgrades, Energy upgrades with PVs and Tenancy agreements for proper maintenance and use of the building.

Main Benefits: Highly sustainable and integrated building systems. Green lease holding tenants accountable for sustainable practices. Average 80 kWh per sqm. 65% energy savings per year equating to $50,000 energy savings associated with 358 tonnes of CO_2 every year.

ACRONYMS

ASBEC – Australian Sustainable Built Environment Council

ASEAN – Association of Southeast Asian Nations

BAS – Building Automated System

BAU – Business-as-usual

BMS – Building Management System

CRC – Cooperative Research Centre

EEC – Energy Efficiency Council

ESD – Environmentally Sustainable Design

EUA – Energy Upgrades Agreement

GBCA – Green Building Council Australia

GHG - Green House Gas

IEA – International Energy Agency

IEQ – Indoor Environmental Quality

IPBES – Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

IPCC – Intergovernmental Panel on Climate Change

IS – Integrated Systems

NABERS – National Australian Built Environment Rating System

NatHERS – Nationwide House

NCC – National Construction Code

NZEB –Net Zero Energy Building

PVs – Photovoltaic Cells

RICS – Royal Institution of Chartered Surveyors

SBEnrc – Sustainable Built Environment National Research Centre

SDGs – United Nations Sustainable Development Goals

UHI – Urban Heat Island Effect

UNFCCC - United Nations Framework Convention on Climate Change

VEU - Victoria Energy Upgrades

REFERENCES

Alam, Morshed & Zou, Patrick & Sanjayan, Jay & Stewart, Rodney & Sahin, Oz & Bertone, Edoardo & Wilson, John. (2016). Guidelines for Building Energy Efficiency Retrofitting.

Ariluoma, M. et al. (2021) 'Carbon sequestration and storage potential of urban green in residential yards: A case study from Helsinki', Urban Forestry & Urban Greening, 57, p. 126939. Available at: https://doi.org/10.1016/j.ufug.2020.126939.

Aronson, J., Clewell, A. F., Blignaut, J. N., & Milton, S. J. (2006). Ecological restoration: a new frontier for nature conservation and economics. Journal for Nature Conservation, 14(3–4), 135-139. doi:10.1016/j.jnc.2006.05.005

Aronson, J., Clewell, A. F., Blignaut, J. N., & Milton, S. J. (2006). Ecological restoration: a new frontier for nature conservation and economics. Journal for Nature Conservation, 14(3–4), 135-139.

ARK Resources. (2022). Nature-Based Cities: Review of Australian ESD Rating Tools https://naturebasedcities.com.au/wp-content/uploads/2022/04/220408-Ark-Nature-Based-City-Initiative-Review-070422.pdf

ARUP. (2019). Low Carbon Futures for Existing Buildings Report.

ASBEC, Climateworks (2017). Building Code energy performance Trajectory project: Issues paper.

ASBEC, ClimateWorks (2018) Built to Perform Final Report

ASBEC, Climateworks. (2016) Low Carbon High Performance Summary Report, Australia. https://www.asbec.asn.au/wordpress//wp-content/uploads/2016/05/160509-ASBEC-Low-Carbon-High-Performance-Summary-Report.pdf

ASBEC. (2016). Low Carbon, High Performance Report: How buildings can make a major contribution to Australia's emissions and productivity goals. http://www.asbec.asn.au/wordpress/wp-content/uploads/2016/05/160509-ASBEC-Low-Carbon-High-Performance-Full-Report.pdf

ASEAN Centre for Energy. (2021) ASEAN Energy in 2022. Indonesia. https://aseanenergy.sharepoint.com/PublicationLibrary/Forms/AllItems.aspx?id=%2FPublicationLibrary%2F2022%2FPublication%202022%2FASEAN%20Energy%20in%202022%20Outlook%20Report%2Epdf&parent=%2FPublicationLibrary%2F2022%2FPublication%202022&p=true&ga=1

Australian Academy of Science (2021). The risks to Australia of a 3°C warmer world.

Australia's Nationally Determined Contribution Communication. (2022) Australian Government Department of Industry, Science, Energy and Resources. https://unfccc.int/sites/default/files/NDC/2022-06/Australias%20NDC%20June%202022%20Update%20%283%29.pdf

Australian Bureau of Statistics (2021), Housing: Census, ABS Website, accessed 26 September 2022.

Australian Conservation Foundation. 60L Green Building Detailed Report. https://d3n8a8pro7vhmx.cloudfront.net/auscon/pages/1369/attachments/original/1475108462/Detailed_report_on_60L.pdf

Australian Human Rights Commission, Monash University (May 2022). RetroFit Kit exhibition (2022) | Australian Human Rights Commission. [online] Available at: https://humanrights.gov.au/our-work/disability-rights/publications/retrofit-kit-exhibition-2022.

Baldwin, C., Matthews, T. and Byrne, J. (2020) 'Planning for Older People in a Rapidly Warming and Ageing World: The Role of Urban Greening', *Urban Policy and Research*, 38(3), pp. 199–212. Available at: https://doi.org/10.1080/08111146.2020.1780424.

Benzar, B.-E. et al. (2020) 'Determining retrofit technologies for building energy performance', Journal of Asian Architecture and Building Engineering, 19(4), pp. 367–383. doi:10.1080/13467581.2020.1748037.

Bevan, W., Lu, S.-L. and Sexton, M. (2020) 'Skills required to deliver energy efficient school retrofit buildings', *Engineering, Construction and Architectural Management*, 27(10), pp. 3051–3073. Available at: https://doi.org/10.1108/ECAM-03-2019-0126.

Beyond Zero Emissions (2020) The Million Jobs Plan: A unique opportunity to demonstrate the growth and employment potential of investing in a low-carbon economy.

Brown, D., Kivimaa, P. and Sorrell, S. (2019) 'An energy leap? Business model innovation and intermediation in the "Energiesprong" retrofit initiative', Energy research & social science, 58, p. 101253.

Buitelaar, E., Moroni, S. and De Franco, A. (2021) 'Building obsolescence in the evolving city. Reframing property vacancy and abandonment in the light of urban dynamics and complexity', *Cities*, 108, p. 102964. Available at: https://doi.org/10.1016/j.cities.2020.102964.

Bush, J and Fornari, G. (2022). Nature-based cities: Greening for sustainability and liveability. Literature review and case studies. Stage 1 Report. University of Melbourne, Parkville.

Camacho-Montano, S.C. *et al.* (2019) 'Clearing the air on EU guidance projects for school buildings.', *Building Research & Information*, 47(5), pp. 624–634. Available at: https://search.ebscohost.com/login.aspx?direct=true&AuthType=shib&db=asu&AN=133290235&site=ehost-live&scope=site&custid=s8849760.

Carr, C., McGuirk, P. and Dowling, R. (2019) 'Geographies of energy transition: the case of high-performing commercial office space in the central business districts of Sydney and Melbourne, Australia', *Australian Geographer*, 50(1), pp. 29–48. Available at: https://doi.org/10.1080/00049182.2018.1536319.

Che Husin, S., Mohd Zaki, N.I. and Abu Husain, M.K. (2019) 'Implementing sustainability in existing building through retrofitting measures', International Journal of Civil Engineering and Technology, 10, pp. 1450–1471.

City of Melbourne. 1200 Buildings Program Advice Sheet https://www.melbourne.vic.gov.au/SiteCollectionDocuments/1200-buildings-advice.PDF

City of Melbourne. (2022). Zero carbon buildings for Melbourne – Discussion Paper.

ClimateWorks Australia. (2018) Tracking progress to net zero emissions. https://www.climateworksaustralia.org/resource/tracking-progress-to-net-zero-emissions/

Climateworks, ISOA, ASBEC. (2020). Reshaping Infrastructure for a Net Zero Emissions Future. https://www.climateworkscentre.org/wp-content/uploads/2020/03/ISCA-CWA-ASBEC-Reshaping-Infrastructure-Issues-Paper-March-2020_FINAL-web.pdf

Climateworks. (2020) Decarbonisation Futures. Australia.

Commonwealth of Australia. (2019) Addendum to the Trajectory for Low Energy Buildings – Existing Buildings.

Crawford, R.H., Stephan, A. and Prideaux, F. (2019) Environmental Performance in Construction (EPiC) Database, The University of Melbourne, Melbourne.

Delivering Net Zero: Key Considerations for Commercial Retrofits (2022) UKGBC - UK Green Building Council. Available at: https://www.ukgbc.org/ukgbc-work/commercial-retrofit-key-considerations/ (Accessed: 9 June 2022).

Douglas, A.N.J. et al. (2021) 'Evaluating and comparing the green wall retrofit suitability across major Australian cities', Journal of Environmental Management, 298, p. 113417. Available at: https://doi.org/10.1016/j.jenvman.2021.113417.

Drosou, V. et al. (2018) Guide to Low Carbon Commercial Buildings – Retrofit, NSW. http://www.lowcarbonlivingcrc.com.au/sites/all/files/publications_file_attachments/lclguide_commercial_retrofit_web.pdf

Eames, M. et al. (2014). Retrofit 2050: critical challenges for urban transitions. [Working Paper]. Cardiff University

Elefante, C. (2012) 'The Greenest Building Is... One That Is Already Built', Forum Journal, 27, pp. 62–72.

Elmqvist, T. *et al.* (2015) 'Benefits of restoring ecosystem services in urban areas', *Current Opinion in Environmental Sustainability*, 14, pp. 101–108. Available at: https://doi.org/10.1016/j.cosust.2015.05.001.

Energiesprong.(n.a.) Energiesprong Website Accessed at: https://energiesprong.org/

Fitzgerald, J. and Laufer, J. (2017) 'Governing green stormwater infrastructure: the Philadelphia experience', *Local Environment*, 22(2), pp. 256–268. Available at: https://doi.org/10.1080/13549839.2016.1191063.

Hoogland, M. (2014). Council House 2 in review. M.AIRAH Exergy Australia

University of Nottingham. (2022). The Energy of Freedom'? Solar Energy, modern slavery and the Just Transition. https://www.nottingham.ac.uk/Research/Beacons-of-Excellence/Rights-Lab/Research-Projects/Solar-Energy-Modern-Slavery-and-the-Just-Transition.aspx

Hyde, R. et al. (2012) Sustainable Retrofitting of Commercial Buildings: Warm Climates. Florence, UNITED STATES: CRC Press LLC. Available at: http://ebookcentral.proquest.com/lib/monash/detail.action?docID=5475834 (Accessed: 16 August 2022). Pp.19

IEA. (2020) 'Buildings' in Sustainable Recovery, IEA, Paris https://www.iea.org/reports/sustainable-recovery

Independent Expert Panel (2019). Interim Emissions Reduction Targets for Victoria (2021-2030). Victorian Government. Melbourne

Infrastructure Australia. (2021) Infrastructure workforce and skills supply Report. pp.29-30

IPCC AR6 WGIII – Chapter 8 Urban Systems and Other Settlements (forthcoming)

IPCC AR6 WIII – Chapter 9 Buildings 2022

IRP (2018). The Weight of Cities: Resource Requirements of Future Urbanization. Swilling, M., Hajer, M., Baynes, T., Bergesen, J., Labbé, F., Musango, J.K., Ramaswami, A., Robinson, B., Salat, S., Suh, S., Currie, P., Fang, A., Hanson, A. Kruit, K., Reiner, M., Smit, S., Tabory, S. A Report by the International Resource Panel. United Nations Environment Programme, Nairobi, Kenya.

Jagger, N., Foxon, T. and Gouldson, A. (2013) 'Skills constraints and the low carbon transition', *Climate Policy*, 13(1), pp. 43–57. Available at: https://doi.org/10.1080/14693062.2012.709079.

Johnson, C., Bell, S., Borrion, A., Comber, R. (2021) 'Working with Infrastructural Communities: A Material Participation Approach to Urban Retrofit', Science, Technology, & Human Values, 46(2), pp. 320–345. Available at: https://doi.org/10.1177/0162243920916235.

Krarti, M. (2018) *Optimal design and retrofit of energy efficient buildings, communities, and urban centers*. Kidlington, United Kingdom : Butterwoth-Heinemann, an imprint of Elsevier.

Lang, M. et al. (2022) 'Energy efficiency in the private rental sector in Victoria, Australia: When and why do small-scale private landlords retrofit?', Energy Research & Social Science, 88, p. 102533. Available at: https://doi.org/10.1016/j.erss.2022.102533.

Liu, Y. (2014) 'Barriers to the adoption of low carbon production: A multiple-case study of Chinese industrial firms', Energy Policy, 67, pp. 412–421. Available at: https://doi.org/10.1016/j.enpol.2013.12.022.

Low Carbon Institute. (2021) Net Zero Carbon Low Carbon Landscapes Guide.

Low Carbon Institute. (2021) Race to Net Zero Carbon: A Climate Emergency Guide for New and Existing Buildings in Australia. https://www.architecture.com.au/wp-content/uploads/2021-11-Net-Zero-Carbon-guide-A-climate-emergency-guide-for-new-and-existing-buildings-in-Australia-1.pdf

Ma, Z. *et al.* (2012) 'Existing building retrofits: Methodology and state-of-the-art', *Energy and buildings*, 55, pp. 889–902. Available at: https://doi.org/10.1016/j.enbuild.2012.08.018.

Mazzarella, L. (2015) 'Energy retrofit of historic and existing buildings. The legislative and regulatory point of view', *Special Issue: Historic, historical and existing buildings: designing the retrofit. An overview from energy performances to indoor air quality*, 95, pp. 23–31. Available at: https://doi.org/10.1016/j.enbuild.2014.10.073.

McKinsey. 2021. Carbon light: How Australia can power ahead in a net-zero world. McKinsey Sustainability Blog. https://www.mckinsey.com/business-functions/sustainability/our-insights/sustainability-blog/carbon-light-how-australia-can-power-ahead-in-a-net-zero-world

Mills, E. et al. (2005) 'The Cost-Effectiveness of Commissioning New and Existing Commercial Buildings: Lessons from 224 Buildings', HPAC Engineering [Preprint].

Mirabella, N., & Allacker, K. (2021). Urban GHG accounting: discrepancies, constraints and opportunities. Buildings and Cities, 2(1), 21–35. DOI: http://doi.org/10.5334/bc.50

Muhammad Khairi et al. (2017). IOP Conf. Ser.: Mater. Sci. Eng. 271 012030

M. Pathak, R. Slade, P.R. Shukla, J. Skea, R. Pichs-Madruga, D. Ürge-Vorsatz,2022: Technical Summary. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.002.

NCC. (2020) Upgrading Existing Buildings. Australian Building Codes Board, Australia.

Oke, C., Bekessy, S., Frantzeskaki, N., Bush, J. Fitzsimons, J., Garrard, G., Grenfell, M., Harrison, L., Hartigan, M., Callow, D., Cotter, B., Gawler, S. (2021). Cities should respond to the biodiversity extinction crisis. 1. 11. 10.1038/s42949-020-00010-w.

Olgyay, V., AIA and Seruto, C. (2010) 'Whole-Building Retrofits: A Gateway to Climate Stabilization', *ASHRAE Transactions*, 116, pp. 244–251. Available at: https://www.proquest.com/scholarly-journals/whole-building-retrofits-gateway-climate/docview/854504575/se-2?accountid=12528.

PIDC-Local Development Corporation. Subgrant Agreement. https://water.phila.gov/pool/files/subgrant-om-agreements-vendor.pdf https://www.pidcphila.com/financing/grants-administration

Prasad, D., Dave, M., Kuru, A., Oldfield, P., Ding, L., Noller, C. & He, B. 2021. Race to Net Zero Carbon: A Climate Emergency Guide for New and Existing Buildings in Australia, Low Carbon Institute.

Rauland, V. and Newman, P. (2015) 'Making It Work', in Rauland, V. and Newman, P. (eds) Decarbonising Cities: Mainstreaming Low Carbon Urban Development. Cham: Springer International Publishing, pp. 205–233. doi:10.1007/978-3-319-15506-7_13.

Royal Institution of Chartered Surveyors (RICS). (2016). Green roofs and walls - Guidance note. https://www.rics.org/globalassets/rics-website/media/upholding-professional-standards/sector-standards/construction/green-roofs-and-walls-1st-edition-rics.pdf

Sayce, Sarah et al. (2022) Resilient Building Retrofits. Milton: CRC Press LLC.

SBEnrc (2019). Closing the gap between design and reality of building energy performance.

Schmidt, M., Crawford, R.H. and Warren-Myers, G. (2020) ' Quantifying Australia's life cycle greenhouse gas emissions for new homes', Energy and Buildings, 224, p. 110287. Available at: https://doi.org/10.1016/j.enbuild.2020.110287.

Sedlacek, S. and Maier, G. (2012) 'Can green building councils serve as third party governance institutions? An economic and institutional analysis', Special Section: Fuel Poverty Comes of Age: Commemorating 21 Years of Research and Policy, 49, pp. 479–487. Available at: https://doi.org/10.1016/j.enpol.2012.06.049.

Soonsawad, N., Martinez, R.M. and Schandl, H. (2022) 'Material demand, and environmental and climate implications of Australia's building stock: Current status and outlook to 2060', Resources, Conservation and Recycling, 180, p. 106143. Available at: https://doi.org/10.1016/j.resconrec.2021.106143.

Threlfall, C., Kendal, D. (2017) The distinct ecological and social roles that wild spaces play in urban ecosystems, Urban Forestry & Urban Greening doi:10.1016/j.ufug.2017.05.012

UK Green Building Council. (2022). Delivering Net Zero: Key Considerations for Commercial Retrofit

UN Environment. (2017). Global Status Report 2017. https://www.worldgbc.org/sites/default/files/UNEP%20188_GABC_en%20%28web%29.pdf

UNFCC. (2022). What is the Triple Planetary Crisis. UNFCC International. https://unfccc.int/blog/what-is-the-triple-planetary-crisis

Valderrama, A. et al. (2015). NRDC Issue Brief – Wanted: Green Acres: How Philadelphia's Greened Acre Retrofit Program is catalyzing low-cost green infrastructure retrofits on private property. USA. https://www.nrdc.org/sites/default/files/philadelphia-green-infrastructure-retrofits-IB.pdf

Victoria Building Authority. (2014). A guide to retrofit your home for better protection from a bushfire.

Wilkinson, S. (2011). The Relationship between Building Adaptation and Property Attributes. Deakin University.

Wilkinson, S. (2013) 'Are Sustainable Building Retrofits Delivering Sustainable Outcomes?', Pacific Rim Property Research Journal, 19(2), pp. 211–222. doi:10.1080/14445921.2013.11104382.

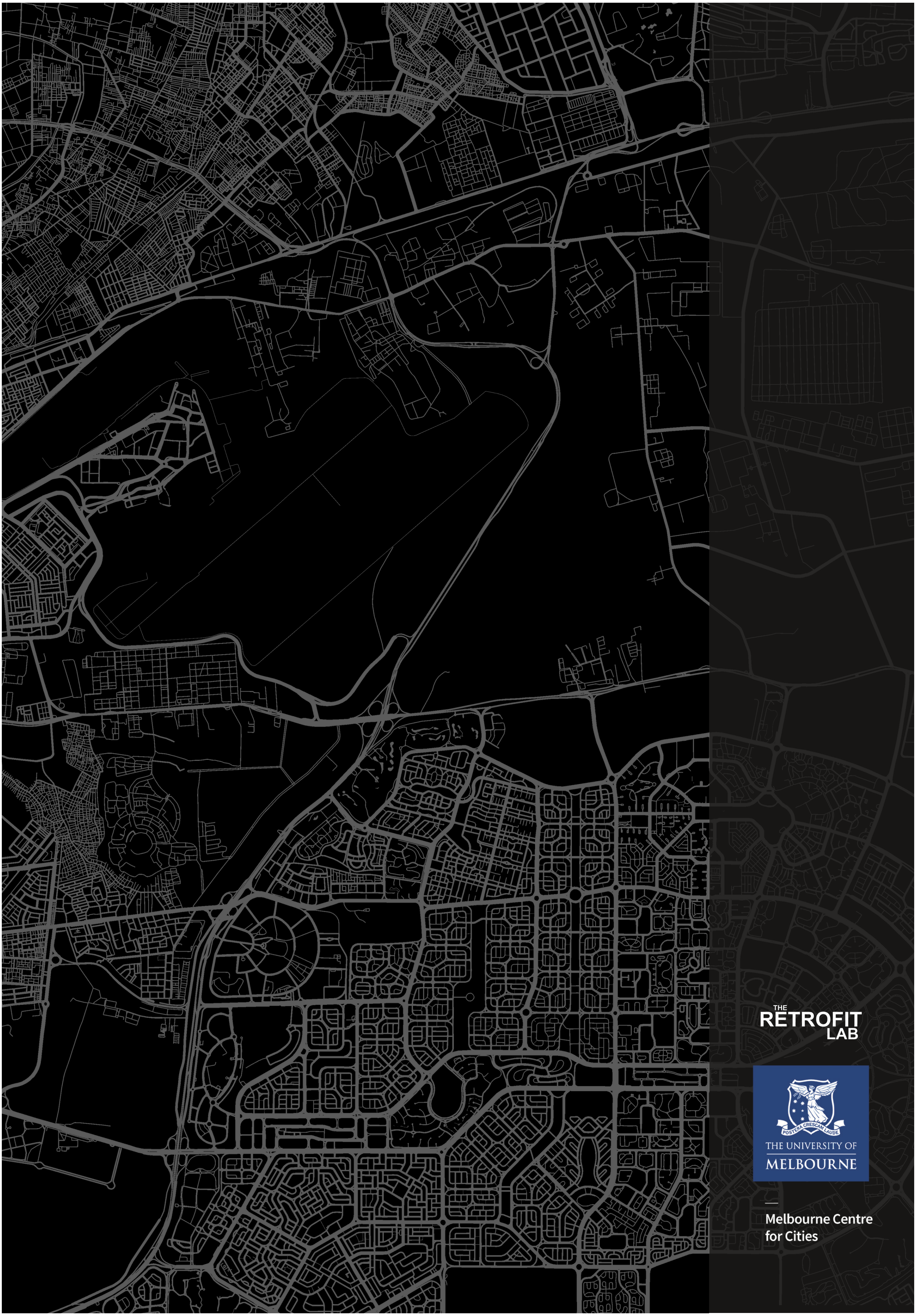
Wilkinson, S. (2013). Sustainable Urban Retrofit Evaluation Technical Report. RICS Research DOI: 10.13140/RG.2.1.4715.5041

Wilkinson, S. (2018) 'Sustainable office retrofit in Melbourne', in. Routledge, pp. 70–82. Available at: https://doi.org/10.1201/9781315622750-5.

Williams, N.S.G., Lundholm, J. and Scott MacIvor, J. (2014) 'FORUM: Do green roofs help urban biodiversity conservation?', Journal of Applied Ecology, 51(6), pp. 1643–1649. Available at: https://doi.org/10.1111/1365-2664.12333.

Yu, M. et al. (2017) 'The Carbon Footprint of Australia's Construction Sector', International High-Performance Built Environment Conference – A Sustainable Built Environment Conference 2016 Series (SBE16), iHBE 2016, 180, pp. 211–220. doi:10.1016/j.proeng.2017.04.180.

Zhivov, A., Lohse, R. (2020). What Is Deep Energy Retrofit?. In: Deep Energy Retrofit. Springer, Cham. https://doi.org/10.1007/978-3-030-30679-3_2



THE RETROFIT LAB

THE UNIVERSITY OF MELBOURNE

Melbourne Centre for Cities