Chapter 7 - Low-tech versus high-technological solutions for a pandemic-adaptable society

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7.1 Introduction

This chapter explores innovations in technology that could bring about significant change to the carbon footprint of existing buildings to address critical issues. Extreme times demand consideration of fresh new approaches. For example, many predict the end of fossil fuels as primary energy sources that facilitated the industrial revolutions of the 19th and 20th centuries in favour of biofuels, nuclear and renewable sources for the 21st century and beyond. Indeed, this is already happening through a combination of investment (public and private) and the impact of legislation and policy. In evidence, the UK's national electricity grid experienced 18 days of fossil-free energy generation in April 2020 (The Guardian, 2020). Can buildings derive sufficient energy from non-fossil sources, and will it need rapidly accelerated rates of retrofitting to achieve the change from fossil fuels and a reduced carbon footprint? Are there other benefits too – such as bioremediation of greywater in buildings? Other innovations in sensors, technology, artificial intelligence and robots may facilitate greater adoption of green infrastructure, which, if adopted 'en masse' in city centres will mitigate the urban heat island effect. One method of distinguishing these innovations is whether they are considered to be 'low tech' or 'high tech'. That is, whether they have little or no reliance on computerised technology (low tech); or whether features such as computer technologies, sensors or artificial intelligence (AI) are integrated into a building ('high tech') for performance optimisation. Drawing on innovations from a range of disciplines, this chapter sets out new technologies, new ideas and new ways of retrofitting existing buildings to deliver more sustainable and resilient outcomes.

Two key issues drive much innovation in the area of sustainable buildings:

a. Embodied carbon versus operational energy

Embodied carbon is defined by the Circular Ecology (2020a) as '*the carbon footprint of a material. It considers how many greenhouse gases (GHGs) are released throughout the supply chain and is often measured from cradle to (factory) gate, or cradle to site (of use)* '. Embodied carbon can also be measured in terms of the 'cradle to grave' framework. This framework includes material extraction, transport, refining, processing, manufacture, the in-use phase (of the product) and, finally, its end-of-life profile. Industry and governments now acknowledge that embodied carbon emissions make up a significant portion of the emissions from the construction sector. Indeed, embodied carbon is estimated between 20% and 50% of the whole lifecycle (embodied + operational) carbon emissions of a new building (Circular Ecology, 2020a). This is a significant proportion and will increase as the thermal standards of new buildings improve, and operational carbon subsequently reduces. Embodied carbon is an important component of net zero carbon buildings (Circular Ecology, 2022) and construction projects and is included in the UK Green Building Council (UK-GBC) Net Zero Carbon Framework definition (UK-GBC, 2019) – for example, in recognition of its significance. Unless the embodied carbon footprint is included in the definition of net zero, it risks neglecting a large amount of upfront carbon emissions.

Taking a whole lifecycle carbon approach to guide our decisions in relation to building interventions is important. As we undertake works to our buildings, we inevitably add embodied carbon through the inclusion of new materials and systems. When specifying materials and systems, the lifespan and performance need to be considered, in addition to the impact these have on the wider building performance. But it is also increasingly important to compare the embodied carbon of the alternative materials for retrofits and other planned works, and through careful, considerate selection of materials and systems, it is possible to mitigate the amount of embodied carbon we add to existing buildings.

b. The three pillars of sustainability – social, environmental and economic

The second issue is the conceptual framework we use to frame our thinking about sustainability. The three pillars formed part of the 1987 UN Brundtland definition of sustainability in respect of inter- and intra-generation equity; that is, meeting the needs of the present generation without compromising the ability of future generations to meet their needs (Circular Ecology, 2020b). These three pillars are informally referred to as 'people, planet and profits'. When considering measures, stakeholders can evaluate the total costs and impacts through consideration of the three pillars and determine the overall best option. There are a number of sustainability decision-making tools in the built environment which adopt this framework (Khoshnava et al., 2018).

7.2 Principles for smart NZE/ZE retrofit to existing buildings

There has been some debate about what constitutes a NZE retrofit of existing buildings.
The concept has roots in research from the 1970s (Esbensen & Korsgaard, 1977). Based on the definition outlined by the European Union's Energy Efficiency Directive (EED) (2018/844, 2012/27/EU and 2010/31/EU), it is the retrofitting of a building that leads to zero or very low energy demand. This energy demand is then primarily met through renewable energy sources, typically on-site or close by.
The principal desired policy outcome is to decarbonise the existing building stock and transform buildings into ones that are highly energy efficient through 'deep renovations'. This reflects indicators presented under Goal 7 of the UN's Sustainable Development Goals, particularly 7.3 which requires doubling the global rate of improvement in energy efficiency in 2030 (United Nations, no date (a)).

The EED requires EU member states to promote equal access to financing, consider affordability and address split-incentive dilemmas, and makes direct reference to the need to alleviate 'energy poverty' through renovation. Therefore, not only does the EDD relate to fuel poverty and energy poverty, a significant issue within the housing stock (Bouzarovski & Petrova, 2015), but it also consequently relates to the concept of energy justice (Gillard et al., 2017). In connection with this, the EED requires EU member states to promote equal access to financing, consider affordability and address split-incentive dilemmas. There is, therefore, a crucial role for NZE buildings to deliver on a number of key elements of EU policy.

An extension to NZE buildings is 'energy positive' buildings. For these buildings, energy surplus to occupant needs is generated through renewable sources and exported to the main energy network or to nearby connected buildings. To be considered 'energy positive', these buildings should produce surplus energy throughout the year rather than during specifi c periods such as in the summer (Magrini et al., 2020).

Given the size of the existing building stock, retrofitting to NZE is crucial to meeting carbon reduction and energy efficiency targets. There are principles and standards which can be adopted to facilitate the delivery of NZE buildings through retrofit. For example, the UK-GBC (2020) highlights 17 opportunities for net zero carbon framed using the RIBA Plan of Works Stages.

EnerPHit is a Passivhaus standard applied to existing buildings (Passivhaus Trust, no date), designed to take into account limitations and challenges that may be present in existing buildings. EnerPHit adopts the Passivehaus Planning Package (PHPP) design tool to facilitate informed design decisions (Passivhaus Institute, no date).

The EnerPHit standard requires that the building achieves a specified energy demand depending on the climate zone the building is located in. For example, for buildings in a cool-temperate zone such as counties in western Europe, this would be a maximum of 25 kWh/m 2 per annum for heating (Passivhaus Institute, 2016). This is a higher heating energy demand than the requirement for the Passivhaus standard for new buildings (i.e. 15 kWh/m^2 per annum), but significantly lower than the average space heating demand of the average home. For example, in the UK the average home has a space heating demand of approximately 145 kWh/m^2 per annum (Mitchell & Natarajan, 2020).

The low heating demand is achieved through high levels of insulation, high performance triple-glazed windows and doors, mechanical ventilation with heat recovery (MVHR) and airtightness of 1.0 air changes per hour. In contrast, for new houses, Passivhaus requires an airtightness of 0.6 air changes per hour, and the 2010 UK Building Regulations (Part L1A) require an airtightness 10.0m^2/(h.m^2) at 50 Pa, although this is expected to reduce to 8.0 m^2 /(h.m^2) at 50 Pa for the 2021 regulations. At the time of writing, these proposed standards were released for consultation in January (closed in April 2021 (UK Gov, 2020a, b).

Beyond adopting standards such as EnerPHit, there are guiding principles for achieving net zero energy and carbon buildings. ARUP (no date) suggests a number of key considerations:

1. Passive building designs to produce less operational carbon and greater levels of occupant comfort;
2. Reusing materials and refurbishing buildings where possible, and use of prefabricated materials to minimise material waste. These approaches can limit embodied energy and carbon, and forms part of circular economy principles;
3. Switching from fossil fuels to electricity as the main power source, and ensuring the use of efficient services and systems with good controls to minimise operational energy and carbon;
4. Reducing operational energy and reducing peak loads through demand management. Supply emissions are high during peak energy periods and reduces infrastructure capacity. The use of smart building technology, automatic load shedding, renewable technology and/or battery technology can facilitate good demand management; and
5. Use on-site renewable technology where feasible and where this would deliver an appropriate solution in relation to lifecycle costs and carbon.

NZE are yet to become common practice. Currently, the perceived challenges of increasing the proportion of NZE buildings include the lack of awareness of NZE buildings; limited or no requirement for NZE buildings within building regulations and standards; actual or perceived higher up-front costs; the availability of affordable finance; and insufficient incentives (Ferrante, 2016).

There has been a burgeoning of technological innovation associated with lowering energy consumption and carbon emissions from buildings, contributing to NZE targets. Some of these innovations are considered to have the potential of being ‘disruptive’ in the sense of, if successful, creating a new market and disrupting current approaches and business models (Wilson et al., 2019). In the realms of architecture and the built environment, ‘low-’ and ‘high-technology’ have been defined in divergent ways. In this chapter, we take these terms to mean built environment innovations capable of delivering reductions in carbon emissions and energy consumption through integration into the building or built environment. This can be in the form of low-technology materials such as strawbales, or high-technology integrated systems such as algae building. However, the terms are not mutually exclusive and are likely to be subject to continual evolution. Ongoing reflection is crucial to ensure that any changes in technology are sufficiently understood and that they are utilised where they are relevant and appropriate to the context. This following sections outline some of the low- and high-technology innovations currently being adopted in the built environment.

7.3 Innovations in technology – bio tech

Some researchers and practitioners look to nature and so called ‘bio technologies’ to provide options for greater resilience and sustainability. This section highlights innovations and options in respect of on-site production of ‘bio energy’ in the form of algae biomass, followed by use of low energy construction materials: hempcrete, strawbale and rammed earth used in wall and floor construction. Each of these materials can be found in most countries and offer proven alternatives to energy intensive concrete.

7.3.1 Algae building tech

In 1839, Alexandre Becquerel discovered the photovoltaic (PV) effect; however, energy generated by PV was inefficient and prohibitively expensive until 1941, when Ohl invented the solar cell. Developments in battery storage, smart electricity grid management and greatly reduced costs, transitioned PV to a viable alternative to fossil fuels. In the 1950s, PV cost AS$2,723.32 per watt in 2016 money. Slowly, then swiftly the cost of solar cells fell to less than AS$1.14 per watt (The Guardian Sustainable Business, 2016). Sudden, disruptive and largely unpredictable technology shifts occur, making technologies viable and attractive (Davila et al., 2012). This occurred with solar and could happen for other ‘new’ renewable energy technologies. Indeed, an example of this was the introduction of the UK’s Feed-in Tariff (FiT) in 2010. The FiT had a number of aims including changing public attitudes towards small-scale low-carbon electricity generation, such as the solar photovoltaic panels; accelerating technological development; and developing the supply chain and stimulating the market. The incentive saw a reduction in the cost of the technology, particularly photovoltaic panels (DECC, 2015). Global biomass energy production reached 88 GW in 2014 (Rosillo-Calle & Woods, 2012); as such bio-energy is no longer a transition energy source.

The BIQ House was constructed in Hamburg in 2013, in a cool temperature Northern European climate. Fifteen apartments are located over four floors plus a penthouse level, with 50–120 metres squared space and a gross floor area approximately 1,600 m² (Buildup, 2015). 200 m² of integrated photo-bioreactors (PBRs) in 120 panels, on two façades, generate algal biomass and heat as renewable energy resources in a low-energy residential building (see Plate 8.1). The façade panel system provides a thermally controlled microclimate around the building, noise abatement and dynamic shading (ARUP, 2016). Construction costs were approximately 5M Euros (Buildup, 2015). How does it work? Microalgae are cultivated in flat panel glass ‘bioreactors’. Each year, the bioreactor façade removes up to six tonnes of carbon dioxide (CO_2) by using flue gas from the gas burner to produce the biomass within the ‘photobioreactors’ (PBRs). Excess heat from these PBRs is used to pre-warm domestic hot water, warm interior spaces or can be stored for later use. Sunlight, constant turbulence and the addition of CO_2 as a nutrient cause the microalgae to grow. This produces heat energy to heat the building, and biomass.

Up to 80% of this biomass is converted into methane via an external biogas plant. Methane is used to fuel the micro-combined heat and power unit to generate both heat and electricity. During the combustion process in the micro-CHP, additional heat and CO_2 are produced, and these are fed back into the system. The heat is recovered via a heat exchanger to contribute to the building’s heating demands, and the CO_2 is used to supply the algae. Any surplus heat from the system can be stored in geothermal boreholes. The heat has 38% efficiency compared to 60%–65% for a conventional solar thermal source. The algae-derived biomass has 10% of efficiency compared to 12%–15% with a conventional PV (Buildup, 2015), so the performance currently does not match alternate renewable energy forms.

The associated heat production of about 40°C (150 kWh/m^2/yr) is reintroduced to the system via a heat exchanger in the heating network or is stored in below ground geothermal boreholes. The boreholes store heat from 16 to 35°C depending on the season. When a higher temperature is required for heating and/or hot water, a heat pump propels the water back into the system. A unit is operated to provide the CO_2 nutrient (flue gas) required by the microalgae in the bioreactor façade and to cover the supply of hot water at 70°C or heating in the energy network (Buildup, 2015).

Microalgae absorb sunlight and the bioreactors also provide dynamic shading, with the amount of sunlight absorbed and shading, dependent on the algae density. When there is more sunlight, the algae grow faster providing more shading for the building (ARUP, 2016). According to ARUP (2016), the flat PBRs on the Hamburg building are highly efficient for algal growth and require minimal maintenance. The PBRs have four glass layers: a pair of double-glazing units creating a cavity, filled with argon gas to minimise heat loss.

Water temperature in the PBRs is controlled by the speed of the fluid flow through the panel, with lower flow rates allowing greater time for sunlight to warm the water as it passes through, and by the amount of heat extracted via heat exchangers in the central plant. The maximum temperature within the PBRs is around 40°C, as higher levels harm the microalgae. Temperature constraints pose challenges to applying the BIQ system in hot countries such as Australia. The relatively low maximum PBR temperature limits the practical use of the extracted heat to mainly a pre-heating function for other building systems. Further, the maximum growing temperature for the algae species used in Hamburg may limit panel use to cooler regions of hotter countries where air temperatures exceed 40°C. However, it is possible to use other algae species, which tolerate higher temperatures.

The total energy system conversion efficiency is 27% relative to the full available solar radiation incident on an unobstructed building roof (ARUP, 2016). PV systems yield an efficiency of 12%–15% and solar thermal systems 60%–65%, when placed optimally to capture the total available solar radiation. Total energy conversion of the BIQ algae system is lower than that of conventional solar hot water panels, the BIQ building's bio-responsive façade necessarily aims to provide energy directly to several building services systems, to provide additional energy benefits through summertime shading, and by providing a biomass stock for additional use.

Take up and acceptance of ABT requires an understanding and view of the system's benefits for owners, users and built environment professionals such as planners, building surveyors, project managers, contractors, quantity surveyors, certifiers property managers and facility managers (ARUP, 2016). However, solar energy innovation has occurred over 181 years to date, costs fell sharply from the 1950s to the 2010s and thus, innovation can transition viability dramatically in short timeframes.

7.3.2 Hempcrete

Another innovative material is hempcrete. Bio-based materials, derived from plant sources, have become increasingly popular, producing eco-friendly materials with a low carbon footprint. Bio-based materials made from renewable vegetable granulates allow materials to have a net carbon storage due to CO_2 fixation during plant growth (Colinart et al., 2012). Among these materials, hemp concrete, or hempcrete, is becoming more and more popular in construction because of its manufacture from renewable resources (plants), and its non-degradable characteristics over time (Amziane & Arnaud, 2013 ; Castel et al., 2016). In comparison with conventional building materials, other advantages of hempcrete are its lower density, excellent acoustic properties (Kinnane et al., 2016;), excellent moisture buffer capacity allowing for the control of interior environmental quality (Khan et al., 2014) and excellent thermal insulation properties (Bennai et al., 2018). Hempcrete is also considered to be 'carbon negative' through carbon sequestration due to the biogenic element of the hemp shivs (i.e. the carbon stored during the growth of the plant) and the non-biogenic element of the lime binder, which absorbs atmospheric carbon for the process of carbonation (Jami et al., 2019).

Hempcrete (Plate 7.2) is a low embodied carbon construction material, here used in wall construction, as a result of carbon storage during hemp growth, and due to the low quantity of binder required compared to traditional concrete. Two types of binders are commonly used in Hempcrete: Ordinary Portland Cement (OPC) or lime. Manufacture of OPC and lime is carbon intensive, involving decarbonisation of limestone.

The thickness of walls has good thermal insulation qualities and results in energy efficient performance. Retrofits involving the reconstruction of walls should consider hempcrete as an alternate material to brick or concrete. There is a need for greater awareness and understanding across the built environment regarding the performance and general properties of hemp as building materials. The material offers opportunities to reduce embodied carbon and enhance general sustainability.

Beyond hempcrete, there are other applications of hemp and lime products being adopted in construction to improve energy efficiency. This includes materials such as hemp-lime plaster, internal lime insulation (Tŷ Mawr, no date (a)) and insulated limecrete floors (Tŷ Mawr, no date (b)). Indeed, hemp-lime plaster has been shown to achieve good thermal properties (e.g. Agliat et al., 2020). The use of such materials may, however, require some additional upskilling and understanding among specifiers and contractors in how to apply these unfamiliar materials (Organ, 2020), and the management of occupant expectations if materials take longer to 'set'.

7.3.3 Strawbale

Straw has been used as a building material for centuries for thatch roofing and it is mixed with earth in cob and wattle and daub wall construction. Strawbales were used for building in the 1800s by settlers in Nebraska, US, shortly after the invention of baling machines. Straw is derived from grasses and is a renewable building material since its primary energy input is solar and it can be grown and harvested. Straw, the springy tubular stalk of grasses, such as rice and wheat, which are high in tensile strength, is composed of cellulose, hemicellulose, lignin and silica. As it breaks down in soil, waste straw can be used as mulch. Furthermore, different grasses have somewhat different qualities; for example, rice straw contains a considerable amount of silica, which adds density and resistance to decomposition. A study from Chile compares wheat straw and corn husk bales (as well as EPS) and although there are similar thermal properties, the compressive strength of corn husks exceeds wheat and EPS (Rojas et al., 2019).

Strawbale walls are highly resistant to fi re, vermin and decay. The structural loadbearing capacity of strawbales is good and, in the loadbearing strawbale method, walls up to three storeys high have been constructed. In Australia, most strawbale construction uses a frame of timber or steel for the building structure to comply with the Building Code of Australia (BCA). In the UK, popular construction forms include loadbearing strawbales or timber frame, such as ModCell, a prefabricated timber and straw structural panel system which has been adopted for a range of applications including housing, education buildings, offices, and retail units (ModCell, 2021).

Strawbales have very low thermal mass, being composed, by volume, mostly of air. However, the cement and earth renders typically used on strawbales result in finished walls having appreciable thermal mass in the masonry 'skins' either side of the insulated straw core. With earthen renders a render skin of up to 75 mm can be achieved, providing significant thermal mass.

With regard to insulation properties, strawbales perform to very high levels and are among the most cost-effective thermal insulation available. Centimetre for centimetre, straw has similar insulation value to fibreglass batts and a typical strawbale wall has an R-value (i.e. the measure of thermal resistance) greater than 10 m^2K/W. Furthermore, dollar for dollar, the insulation value of a strawbale wall exceeds conventional construction. It is essential that roofs and windows are well insulated to maintain the overall performance of strawbale construction.

Another attribute of strawbale construction is its excellent cost-effective sound insulation, which contributes to the liveability of this form of construction. Further, as fire cannot burn without oxygen, given strawbales are tightly packed and covered with render to produce dense walls with a nearly airless environment, the fire resistance of compacted straw is very good. In Californian bushfires that destroyed conventional structures, strawbale homes survived.

In 2002, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), an Australian Government agency responsible for scientific research, on behalf of Ausbale and the South Australian fi re authority, undertook tests to produce a two-hour fi re rating. The three types of standard sized rendered strawbales – earth; lime and sand; and lime, sand and cement, were subjected to a simulated bushfire front with a maximum heat intensity of 29 kW per square metre – an accepted standard under AS 3959, Construction of Buildings in Bushfire Prone Areas. Further, a completed wall has excellent resistance to vermin and the typical termite protection measures required in the BCA are generally sufficient. However, contractors need to prevent infestation of mice during construction when the bales are relatively unprotected. Most strawbale construction is coated with plaster or render which is adequate to keep animals out, and if they do manage to get inside, densely packed straw makes it hard for them to navigate through the space. During construction, the use of traps and baits can be considered to ensure the finished structure is sound and vermin-free.

Provided the straw is protected and not allowed to get waterlogged, strawbale buildings may have a lifetime of 100 years or more (Seyfang, 2010). The most detrimental factor affecting strawbale wall durability is long term or repeated exposure to water. After two or three weeks, the fungi in bales produce enzymes that break down straw cellulose if the moisture content is above 20% by weight. The best way to prevent rot in a finished structure is to create a waterproof, breathable wall. The survival of historic strawbale structures in Nebraska demonstrates their durability in climates with variable moisture and temperature.

Straw is a waste product which cannot be used for feed, unlike hay, and much is burned at the end of the season. Using straw for building reduces air pollution and stores carbon. The straw left over from building can be used as much so that, overall, there is minimal waste from using the material (see 'Waste minimisation'). To be sustainable in the long term, straw needs to be grown in ways that maintain soil quality. Strawbale walls usually require concrete footings which adds to the embodied energy of their construction. Rice straw is a by-product of irrigation agriculture that changes the flow and water balance of catchments in Australia's major river systems. Wheat straw is less water intensive.

Greenhouse gas emissions associated with strawbales are very low. For example, a tonne of concrete requires more than 50 times the amount of energy in its manufacture than straw. Using straw for building will store carbon that would otherwise be released but the amount sequestered per dwelling is relatively small. Straw's primary value is as an insulating material that enables houses to use less energy in operation and have lower carbon dioxide emissions over the building's life.

7.3.4 Rammed earth

Globally, there has been a range of earth-based construction adopted historically such as cob, clay lump and adobe. Variations of types, mixes and techniques were seen not just between countries but also regionally and locally. Rammed earth walls are formed by ramming selected aggregates: sand, silt, gravel and clay into place between flat panels known as formwork. Traditionally, construction workers repeatedly rammed the end of a wooden pole into the earth mixture to compress it; hence the name 'rammed earth'. Nowadays the pole has been superseded with a mechanical ram. Even so, it is perceived as a low-tech option, adopting traditional materials and methods of construction, working with the site and the climate.

Globally, thousands of unstabilised rammed earth buildings have survived many centuries of use. However, most contemporary rammed earth walls are built with cement as a stabiliser and are typically 300 mm thick for external walls and 300 mm or 200 mm for internal walls. Stabilised rammed earth includes around 5%–10% cement to increase the strength and durability of the material. Stabilised rammed earth walls are usually covered with an air-permeable sealer to also increase the durability of the material.

Most embodied energy or rammed earth is derived from quarrying the raw material and transportation to site. Therefore using on-site materials will reduce construction-related embodied energy. Rammed earth has excellent thermal mass but limited insulation, so depending on the building's location, insulation may be needed.

Wall colour is related to the earth and aggregate used. Ramming layer by layer can lead to horizontal stratification to the walls, which can enhance the overall appearance. It can be adopted as a feature or eliminated depending on the preference. Also, the aggregates can be exposed and special effects created by adding different coloured material in layers, and feature stones or objects, alcoves or relief mouldings. Unusual finishes can be formed by including shapes in the formwork that can be released after the wall has been rammed.

7.4 Innovations in low and high technology – AI and smart tech

We need our buildings to be good energy citizens. This means that they need to consume less energy through energy efficiency and energy optimisation. It is essential that we reduce their energy demands on national energy networks and contribute to those networks through on-site renewable energy generation. This can be achieved not only through digitalisation and the interoperation of key technologies but also through carefully modelling solutions on an individual building level and a larger building stock level. However, technologies should be selected where they represent value to the owner or occupiers to ensure usefulness and also to avoid adding unnecessary complexity and embodied carbon to a building.

Through industry and research collaborations, supported by funding, there has been a burgeoning of innovative technological approaches to enable the retrofitting of the existing building stock to deliver nZEBs (e.g. Elagiry et al., 2020). From projects such as RenoZEB which utilises prefabricated 'plug and play' systems to Energiesprong which uses a prefabricated package of measures financed by energy bill savings to deliver net zero energy buildings.

On a microscale, technologies such as 'smart thermostats' have been growing in popularity, although the realised energy savings resulting from these types of technologies remain highly variable, often dependent on user assimilation, settings and behaviours (Stopps & Touchie, 2021). However, when compared to conventional thermostats, smart thermostats may facilitate greater opportunities for energy and carbon savings through improvements to the user interface, enabling improved scheduling (Stopps & Touchie, 2021). Used in the right way, such technologies have the potential to empower building users to reduce energy consumption.

7.4.1 Energiesprong

Energiesprong (translated as 'energy leap) is a Dutch energy transition programme currently active in the Netherlands, Canada, France, Germany, Italy and the UK, as well as cities such as New York. The premise of the programme is to provide whole house refurbishments at scale, with the intention of building critical mass, stimulating the wider market to enable a good business case, innovative solutions and financing mechanisms.

Through 3D laser scanning of an existing house, a building information model is then developed, and this is used to produce technical drawings. These then guide the decisions and production of customisable prefabricated packages at 'flexible factories'.[1] On site, these complete refurbishment packages take between 1 and 10 days to install, after which the house should be net zero energy. The package of measures can incorporate prefabricated facades, insulated roofs with solar panels and smart heating, ventilation and cooling technologies. A long-term warranty of up to 40 years is provided against the indoor climate and energy performance of the property following the refurbishment.

Monitoring equipment is installed with a real-time display for occupant feedback about their energy consumption, and to enable any issues to be identified where expected energy consumption is exceeded. The refurbishment of each home is financed through the savings on the energy bills against a payback period of 40 years. Through this, instead of paying energy bills the occupant pays an 'energy plan'.

7.4.2 Smart buildings

Buildings are increasingly embedding sensors and similar components to enhance their energy systems. This can result in the creation of more complex, networked cyber-physical systems which artificial intelligence can be designed to optimise.

Smart buildings incorporate multiple sensors, subsystems and actuators to facilitate automated monitoring and control of energy and the internal environment. In NZE buildings, it can help reduce energy consumption, thereby reducing the associated energy costs and carbon emissions. Algorithms are used to analyse datasets, and in the context of NZE buildings, AI will monitor, collect information, control, evaluate and manage energy consumption to enable energy savings whilst producing more comfortable internal environments for occupants. When used in conjunction with other technology such as 'big data', the cloud and the Internet of Things, AI can enable the active management of electricity grids beyond individual buildings through improving the accessibility of renewable energy systems in buildings (Farzaneh et al., 2021).

The particular challenges associated with smart buildings include concerns around security and data privacy. Smart buildings need to prove their long-term reliability and demonstrate their ability to contribute to what Farzaneh et al. (2021) call the 'betterment of society'.

7.4.3 Smart batteries

Low carbon, 'renewable' technologies are reliant on the availability of the energy source, such as sunlight and wind. By their nature, many of these energy sources are intermittent and may not coincide with when energy demand is greatest. For example, pre-Covid-19 in the UK, demand for electricity has typically been found to be greatest at around 8 a.m. and 5 p.m. (Department for Energy and Climate Change, 2014), varying slightly by season and between countries. Electricity consumption patterns altered slightly during Covid-19 lockdowns, resulting in the morning electricity demand peak shifting slightly later (National Grid, 2020). However, sunlight energy is greatest at

noon, and we typically receive more power between 11 a.m. and 3 p.m. (NASA Earth Observatory, 2009).
For the renewable technologies integrated into our buildings, where a surplus of electricity is generated above demand, this can either be transferred to the national electricity grid or stored locally if the system includes battery storage. Where the peak times for renewable electricity generation does not complement peak consumption times, batteries offer the advantage of increasing the amount of renewable-generated electricity available.

Batteries add to the initial cost of a renewable technology system, but also potentially to the lifetime costs and embodied carbon/energy of the system, given that the current lifespan of such batteries are between 5 and 15 years. In contrast, the estimated lifespan of solar (photovoltaic) panels is currently around 30 years, necessitating the replacement of the batteries during the lifetime of the panels. However, a further consideration is the environmental impact of producing and disposing of batteries, which require the mining of minerals and metals. This results in environmental harm. Batteries need carefully disposing of and whilst recycling is an alternative, this can currently degrade their power.

There are various types of batteries, and the technology has rapidly developed over recent years (Wang et al., 2018). One development has been the integration of AI. AI can monitor patterns and vast amounts of data, then learning from this for energy optimisation (Boretti, 2021). Whilst the technology is being investigated for application on a city-scale such as NEOM, a new city being planned in Saudi Arabia, AI-enabled solar batteries are currently being used for individual buildings. In housing, such systems identify the recent energy generation from the solar (photovoltaic) panel and household's consumption patterns. It then takes into consideration the local weather forecast and the property's energy tariff. Using this information, it predicts the amount of solar energy the system is likely to generate and how much the household is likely to use.

Where the renewable technology does not produce sufficient electricity to meeting demand, coupling with an energy supplier who generates 100% of their electricity from renewable sources can help keep the operational carbon footprint of the building low. In housing, where occupants adapt to use electricity from their supplier at off-peak times and stored electricity from their battery at other times, this can also facilitate a reduction in peak loads and therefore strain on the national electricity grid, but also reducing utility bills where lower, off-peak tariffs are utilised (Octopus Energy, 2018). This has potential implications for 'energy justice' (Villavicencio Calzadilla & Mauger, 2018), which relates to the UN Sustainable Development Goals, particularly Goal 7 – ensure access to affordable, reliable, sustainable and modern energy for all (United Nations, no date (b)).

7.5 Delivering more sustainable resilient outcomes with new tech

There are many debates about whether new tech can deliver more or less sustainability and resilience in buildings. The argument often posited for new tech is that adoption of sensors, AI and computer technology can optimise building performance. This section highlights a new innovation that could facilitate more sustainable and resilient retrofit outcomes; here in respect of maintenance and upkeep of green walls; traditionally found to be a technology with high ongoing maintenance costs and needs.

7.5.1 Wallbot and Smart Green Walls

The benefits of urban green infrastructure (GI) are widely accepted and include urban heat island attenuation, increased biodiversity, reduced carbon emission, biophilia effects, provision of spaces for social interaction, attenuation of rainwater flooding and improved air quality (Wilkinson & Dixon, 2016). The opportunity for robotic technology to increase the uptake of green walls and facades whilst reducing OHS and maintenance costs is clear. A 2019 University of Technology Sydney (UTS) research project examined the advantages of using a new technology to inspect, monitor and maintain green walls on the side of infrastructure and buildings. With climate change and increasing temperatures a stark reality for all of us, resilience and liveability, as well as sustainability, are greatly enhanced through the adoption and retrofit of GI. Despite the advantages of GI, adoption rates are low, mainly due to the perceptions of onerous, ongoing maintenance costs and, on high rise buildings, OH&S issues. Horizontal farming bots are well established, and from this the wallbot was conceptualised. An extensive literature review of existing robots and wall climbing mechanisms, power sources, pruning technologies and green waste collection, as well as sensor technology and costs, was undertaken prior to workshops with NSW industry stakeholders, Junglefy and Transport for NSW, who critiqued the proposed wallbot designs. Based on the experts' review, a prototype design based on a four-cable climbing mechanism was designed and prototyped at UTS. This wallbot has sensors to detect plant growth, health, shape, temperature and to create a 3D map of the plants that can be updated over weeks, months and years. This research is now evolving to Smart Green Wall technology, where the control system for wallbot is integrated in the Building Management System (BMS) for maintenance and record keeping purposes. This technology will lower OHS risks and reduce ongoing maintenance needs and costs. It creates a new local industry for bot manufacture, bot installation and maintenance.

7.6 Conclusions

Adaptations, or building retrofits, can take many forms. This chapter has explored low and high tech options that are emerging as innovations in technology and their place in decision-making. The case of embodied carbon versus operational energy consumption was discussed with reference to taking a whole lifecycle, or 'cradle to grave', approach. Embodied carbon is important and forms part of net and nearly zero carbon targets for buildings and should be considered in decision-making. However, the three pillars of sustainability: social, environmental and economic factors also need to be taken into account. NZE principles and ways of achieving this in retrofits were also outlined and how the aim is to decarbonise existing stock through deep renovations. Going one step further, it is possible to make buildings carbon positive; where surplus energy is exported to the grid or energy network. Various options, schemes and frameworks to achieve NZE or carbon positive retrofits were outlined, with options being adoption of low, high and bio tech. Examples of low tech approaches are strawbale construction, whereas bio tech options include algae building technology with biomass grown in façade panels for conversion to biofuel. Other bio tech option includes hempcrete, where hemp is a binder which reduces the embodied carbon in the finished material. Approaches can use both low and high tech. An example of this is Energiesprong, which utilises technology to 3D scan buildings to inform the selection and adoption of prefabricated measures, enabling rapid NZE retrofits when on-site, funded by savings on energy bills. Technology is included to locally generate energy as well as for monitoring building performance. The latter can highlight potential issues where an energy performance gap arises.

Smart buildings use multiple sensors, subsystems and actuators to facilitate automated monitoring and control of energy and the internal environment. As such they optimise operational energy use and comfort. At precinct scale, AI can facilitate active management of electricity grids and improve accessibility to renewable energy systems. As a new innovation, there is less evidence of their performance over time, but this will change. AI is being incorporated into technology such as batteries, resulting in 'smart batteries'. These smart batteries analyse data on recent energy consumption patterns and weather forecasts to assess the amount of energy – for example, from solar photovoltaics is likely to be generated. This can not only support reducing peak loads to the electricity network, but it can also facilitate occupant behavioural changes, conscious carbon footprint reductions and lowering of energy bills where off-peak electricity tariffs are used to meet any deficit in on-site electricity supply.

Another innovation is the green wallbot. Green walls offer enhanced thermal performance and reduced energy consumption. However, a barrier to uptake includes perceptions of high maintenance costs and OH&S issue for maintenance staff. These are overcome through wallbot.

The well-being of future generations must be factored into the decisions we make now. Our current mainstream and previous methods of construction did not factor carbon; embodied and operational, into decision-making. This is changing. However, given that only 1%–2% is typically added to the total stock of buildings, it is in retrofit that our greatest chance to decarbonise our built environment lies. Finally as we emerge from Covid-19, with new knowledge and experience our ability to deliver more resilient building retrofits also offers the opportunity to rebuild economies.

Note

1 Defined as the ability of a factory to produce customisable packages (i.e. different dimensions and solutions) to reflect the heterogeneous housing stock.

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