Resource Efficient Housing for 2020

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For Zero Waste Scotland

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EUROPE & SCOTLAND

Contents

1 Introduction

The study is principally intended to reveal how well the construction industry can deliver an affordable resource-efficient house in 2020 and to develop a brief for this based on available knowledge, precedents, methods of working, materials, products, technologies, challenges and barriers. It is also intended to inform Zero Waste Scotland (ZWS) what the objectives of a hypothetical new demonstration resource efficient house (REH2020) would be.

This study began from a point of view of looking at the changes in the construction sector since the construction of the REH2013[1] at Ravenscraig in order to inform the construction of a hypothetical REH2020. It rapidly became clear that changes in global understanding of anthropocentric caused environmental harms outweigh changes in the construction sector in the same period. The research was therefore based on an understanding that the solutions required go far beyond anything envisaged during the design and specification of the REH2013. Section 7.4 is devoted to the possible potential further uses of the REH2013.

The last few years has seen significantly raised awareness of anthropocentric pollution, resource depletion and waste generation and the resulting severe adverse impacts on climate and loss of biodiversity.

Recognition of the global and local contribution of the construction sector is now well acknowledged and importantly, the role of buildings and the built environment in mental and physical health & wellbeing are also on a rising curve in research and education.[2,3] This has created motivation for the radical changes that we are now required to make in house-building. The gulf between what is currently being delivered and what is now recognised as required is vast.[4]

In respect of climate change, the latest IPCC report 2018[5] represented a fundamental shift in thinking by moving the debate from a country-by-country requirement to limit carbon dioxide (CO_2) emissions to a global requirement to not exceed a threshold level of atmospheric CO_2.[6] The IPCC report makes it clear that the global world must achieve net zero CO_2 by 2050. Many nations have set legally binding agreements to achieve or surpass this. Scotland has set a date of 2045 to achieve net zero of all greenhouse gases.[7] Edinburgh and Glasgow are seeking to meet a target date of 2035. The repercussions will be hugely significant.

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[1] [1] From Resource Efficient House ADS case study
[2] https://www.ukgbc.org/health-and-wellbeing/
[3] https://www.hw.ac.uk/uk/study/postgraduate/health-wellbeing-built-environment.htm
[4] https://www.businessgreen.com/bg/news/3085100/business-as-usual-is-dead-global-resource-use-smashes-past-100-billion-tonnes
[5] https://www.ipcc.ch/sr15/
[6] https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/
[7] The Climate Change Bill commits Scotland to a target of net-zero emissions of all greenhouse gases by 2045. This is tougher than a net-zero carbon target, which commits only to balancing CO_2 emissions. The plans cover a 15 yr period from publication. https://www.gov.scot/news/scotland-to-become-a-net-zero-society/zero-society/

In Scotland “the current Net Zero Carbon focus in buildings is in the direct carbon from the construction process and the in-life carbon, mainly energy and heat.” [8] This is compounding the problem of creating realistic solutions as it represents a huge underestimation of the real impacts of buildings and the built environment and consequently the role that they must play in achieving Net Zero Carbon. This focus also fails to recognise that carbon dioxide (CO_2) is only one of the very many pollutants caused by human activities that are adversely affecting our human environment and damaging biodiversity.

By 2030, buildings and the built environment must address the contributing elements of land loss, transport, materials, water consumption, pollution, waste, toxicity and health & well-being. Inevitably it will be necessary to evaluate unintended consequences of current policies – such as recycling and planning – where they undermine the Net Zero ambition.

In respect of materials, it is now becoming clear that the utilisation of physical resources globally is far beyond what can be sustained. Globally we are exceeding the Earth’s regenerative capacity for natural resources and recycling only a fraction of that available.[9]

In Scotland the established target of 70% for recycling of Construction & Demolition Waste (CDW) is easily reached.[10,11,12,13] However, this is against a rising quantity of actual CDW, across almost all types. Higher rates of recycling, to divert waste from landfill, simply disguise the true quantities. While it in principal recycling contributes to the ‘circular economy’, the circle is rapidly expanding.[14] Most materials and products are also downcycled with loss of intrinsic qualities and hence value.

The recycled materials are far from carbon neutral as most require transportation, need additional energy and create further pollution through remanufacturing. The circular economy should not be used to justify the re-use and re-processing of materials and components toxic to health or requiring high energy processing.

Recycling as policy also often fails to recognise important issues about waste and the creation of new ‘monstrous’ hybrids[15] that can never be separated and are destined to be the most problematic waste materials – in perpetuity.

For the circular economy to become a reality, and hence allow us to have ongoing access to resources in perpetuity, then the current attitude to recycling and manufacture must change profoundly. New thinking is required regarding acceptable materials and products and extension of life of existing resources, although there is significant existing guidance.

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[8] Stephen Boyle ZWS – correspondence March 2020

[9] https://www.footprintnetwork.org/2019/06/26/press-release-june-2019-earth-overshoot-day/

[10] Table 2. https://www.sepa.org.uk/media/500273/waste-from-all-sources-summary-document-and-commentary-text-2018.pdf

[11] 2017 Waste Data Quality Report, SEPA and Natural Scotland

[12] It is unclear whether remodelling, redecorating and refurnishing is included in the data for CDM waste. ‘Churn’ - frequent major rearrangement was an issue in office buildings in the 90’s http://www.fmguru.co.uk/cmsfiles/a-z/churn.pdf -. Flat screens, wifi, mobiles, laptops and hot-desking has reduced this. If now dominated by domestic projects, it’s inclusion as CDM waste might focus on useful measures.

[13] http://www.gensleron.com/work/2018/8/21/six-steps-to-conquer-workplace-churn-and-maintain-reliable-d.html

[14] https://www.environment.gov.scot/data/data-analysis/waste-from-all-sources/

[15] https://sustainabilitydictionary.com/2005/12/03/monstrous-hybrid/

This study looks to a wide concept of pollution, and the breadth of relevant wastes, to identify features of a contemporary REH2020 and develop these into a brief. It recognises that there are very many types of pollution and waste at different stages through a building life cycle. Waste occurs in planning, design, material selection and in use. This waste has consequences in urban and rural contexts. Design life is far too short.

There is waste of land and money as low-density buildings eat up valuable green space whilst offering no bio-diversity response. Waste occurs on site, through inefficiency, over ordering, adverse weather, travel and transportation. Waste in use is perhaps least reported. It occurs through less than optimal performance and - when located remote from existing social and transport infrastructure - enforced inefficient behaviours and ill-health, often driven by lack of local amenities – societal waste. All must be tackled to achieve genuinely net zero resource use in construction, occupation and disposal of buildings.

Vital aspects of future proofing not being addressed include affordability, social integration, minimizing energy demands, climate change resilience, social equity, health and well being and providing for an aging population. There is inadequate supply of housing. Housing in Scotland by 2030 needs to conform to the resource limits of 1–planet living and with climate emergency quite clearly in our sights this must become a fundamental requirement. If linked with a compassionate social agenda it could create beneficial environmental and social outcomes.

A major outcome of this study is that a future project must start from a position of fully comprehending the changes required, look to contemporary best practice and work with those in a position, able and willing to lead that change and empower them to do so. Business as usual cannot continue if we are to meet the target. This may require some uncomfortable decisions to create the required shift.[16]

A specific requirement of this study was that it address mainstream construction and offer innovative thinking. This is a helpful constraint. In the recent past too much innovation, research and development has occurred on the periphery and it has not been properly valued, respected, rewarded or incorporated in policy change. The findings of this report can assist policymakers to transform house building and thereby to deliver the resource efficiency that is vital to our future.

It is apparent from experience that mainstream change will not happen voluntarily. Consequently, as the mainstream must be part of the solution, then the ultimate mainstream devices – education, training, regulation and planning policy – are required to create the necessary change.[17]

To fail to take account of the facts, our current perilous predicament, and the scale of the response required, would be to waste the opportunity presented here. At this moment, time and opportunity are amongst our most precious resources and to waste them would be nothing less than tragic.

16 https://www.businessgreen.com/bg/news/3085100/business-as-usual-is-dead-global-resource-use-smashes-past-100-billion-tonnes

17 https://www.nidirect.gov.uk/articles/what-building-regulations-protect

The Building Regulations are intended to protect people's safety, health and welfare in and around buildings. The regulations are also designed to improve conservation of fuel and power, protect and enhance the environment and promote sustainable development.

2 Structure of the Report

This Report looks at the current context, issues that need to be addressed, exemplars that can provide guidance and establishes the overarching principles of a brief for affordable resource efficient housing (REH2020).

Section 3 sets the scene by addressing the change of context between 2013 and 2020. In particular the change in global understanding of anthropocentric caused environmental harms.

Section 4 presents the outline of issues to be addressed in developing a brief for resource efficient housing. This is based on an analysis of the types of waste and how waste occurs at each stage of the pre-design, design, construction, in-use and end stages of building life.

A number of case studies are discussed in Section 5 and cover the overarching principles of scale, density, materials, place, lifespan and targets that should underpin a truly resource efficient 2020 house.

Section 6 brings together the process aspects of Section 3 with the overarching principles identified in built exemplars in Section 5. It summarises the issues and targets that should be embodied as key messages in a 2020 demonstration of resource efficient housing. These require to be communicated through mainstream devices such as regulation and planning policy as the drivers of future housing supply.

Section 7 brings together the main findings that define the objectives of a hypothetical REH2020 project, future research requirements. It ends with a number of recommendations.

Section 8 looks briefly at the regulatory context and Section 9 summaries some of the main findings.

3 State of Play 2020 - Changing Context

3.1 Background

The last few years has brought immense change in our understanding of how human behaviour is affecting the Earth. Our understanding of climate change, resource depletion, waste, pollution in many forms and loss of biodiversity is hugely significant to the construction sector and must be major considerations in addressing future needs.

There has been increasing recognition that our relationship with the Earth is synergistic. There is now overwhelming evidence that increased extreme weather, flooding, drought, as well as fire and air pollution are all in part caused by how humans live on the planet and this threatens other species and our current and future health, wellbeing and even survival.

Although many leading individuals, professional practices and organisations have been lobbying for change for many years this stark realization of mutual dependency has enhanced motivation. It led to a call to address science and facts, which proved alarming, and 2018 was a significant turning point in the recognition of human impacts on the global environment that created a surge in grassroots climate and environmental activism.[18] The whole of the construction sector now needs to change radically to address these challenges in line with very best practice.

The context for the current work is therefore the serious challenges that we face: -

- Construction is responsible for half of global waste production
- Expected population increase in Scotland to 2043 of 2.5% (~136,000 people)[19]
- Climate crisis
- Material Scarcity
- Waste & Pollution
- 6th mass species extinction[20]
- Public health crisis including recognition of humans as a social species and the mental and physical health benefits of the natural environment [21]
- Much greater understanding of the role of the Circular Economy
- Numerous New and Emerging Concepts in Housing Delivery to seek to meet the challenges.

3.2 Global & Local Situation – Climate

In 2018 the Inter-governmental Panel on Climate Change (IPCC) issued a warning to make clear that the international community is not on track to meet Paris Climate Targets, *SR-1.5°C*.[22] It stated that unless we undergo *“unprecedented societal transformation”* to rapidly decarbonize by 2030 we will

18 Thunberg G., (2019) – never too small to make a difference
19 https://www.nrscotland.gov.uk/statistics-and-data/statistics/scotlands-facts/population-of-scotland
20 Notably the first directly linked to human activity –Burtynksy– The Anthropocene Project
21 Natural England 2016 Access to Evidence Information Note EIN018 Links between natural environments and mental health: evidence briefing
22 Herzog H.J., (2018) The Special Report on Global Warming of 1.5 °C (SR15) MIT

surpass 2°C of global heating. The huge significance of the 0.5°C difference, which led to a growth of activism, is illustrated, below.

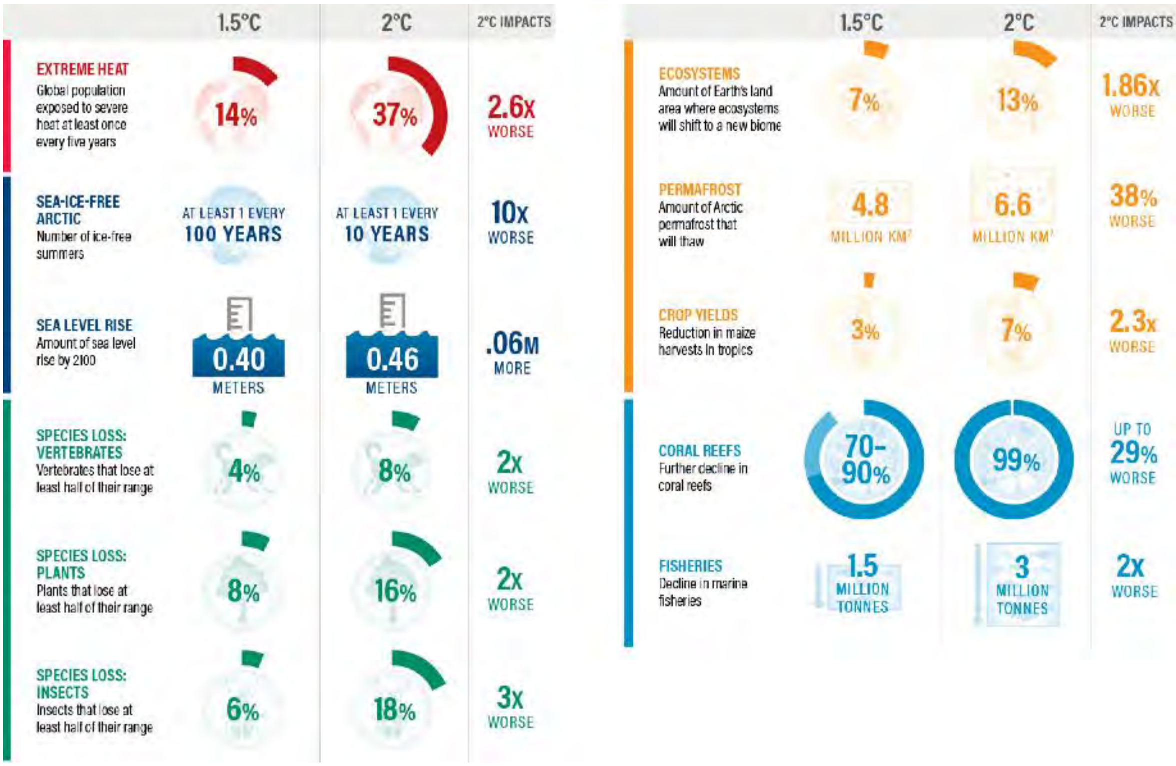

Image 1: Difference in Impacts at 1.5 and 2.00C change– Source: IPCC (2018)23

The IPCC identified a need for societal change. This is important and has reinforced calls for “New Professionalism”.[24] Professionals in the built environment have responded. In Scotland action has been spearheaded by The Royal Incorporation of Architects in Scotland (RIAS), the Scottish Ecological Design Association (SEDA), The Anthropocene Architecture School (AAS) and Zero Waste Scotland (ZWS). In the wider UK, Architects Declare, The London Energy Transformation Initiative (LETI), the Royal Institute of British Architects (RIBA) *2030 Challenge*, and the UK Green Building Council - Advancing Net Zero campaign have all been active.

In April 2019 Scotland declared a Climate Emergency and, with the passing of its Climate Bill in June 2019, set a legally binding target to be Carbon Neutral by 2045. Both Edinburgh and Glasgow City Councils then set IPCC-compliant targets aiming to be carbon neutral by 2030. The target is ambitious, but according to the Centre for Alternative Technology’s *Zero Carbon Britain Report: Rising to the Climate Emergency*,[25] possible with existing technologies.

Notably, the UN climate negotiations conference, COP26, will be hosted in Glasgow in 2021 (postponed due to the COVID-19 pandemic). This follows the COP25 meeting in Madrid that failed to

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23 https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/
24 https://www.researchgate.net/publication/263145329_A_new_professionalism_Remedy_or_fantasy
25 CAT 2019 Zero Carbon Britain - Rising to the Climate Emergency CAT

strengthen global efforts or to reinforce the Paris Climate Agreement. COP26 is therefore an important opportunity for Scotland to demonstrate commitment and new thinking to develop scalable decarbonised solutions and this provides a catalyst to accelerate development in the Scottish construction sector.

Of significant relevance to the current and local context is progress made in Scotland to decarbonise. Scotland's emissions from electricity generation currently stand at 0.024 $kgCO_{2(e)}$/kWh compared to the UK figures as a whole of 0.256 $kgCO_{2(e)}$/kWh and recent estimates for China of 0.753 $kgCO_{2(e)}$/kWh.[26] This is a significant achievement and provides opportunity to consider numerous policies. If we are to genuinely contribute to reducing global emissions - in the spirit of the IPCC requirements - then we need to seriously address our relationship with imported products and the regulations that require them – such as imported high embodied energy PV panels - that should be open to close scrutiny in terms of their overall global benefit.

3.3 Global & Local Situation - Material Resources and Waste

In 2019 Earth Overshoot Day, the date each year on which we surpass the Earth's regenerative capacity for natural resources, fell on 29th July, its earliest date in history (Global Footprinting Network, 2019).[27] The Circularity Gap Report that followed was launched at the World Economic Forum (Davos 2020). It estimates only 8.6% of 100.6 Bn tonnes of minerals, fossil fuels, metals and biomass that entered the global economy in 2017 was reused.[28] Materials scarcity is becoming a fact.

In Scotland the proportion of Construction & Demolition waste (CDW) that is produced and recycled is quantified.[29] A 70% recycling target to divert waste from landfill is achieved every year but the amount of waste being generated in construction is increasing across almost all waste types.

Image 2: Graph: Construction and demolition waste by type: 2011-17

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26 https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019
27 https://www.footprintnetwork.org/2019/06/26/press-release-june-2019-earth-overshoot-day/
28 https://www.businessgreen.com/bg/news/3085100/business-as-usual-is-dead-global-resource-use-smashes-past-100-billion-tonnes
29 https://www.environment.gov.scot/data/data-analysis/waste-from-all-sources/

Current policy is generating new markets in recycling and reuse but, whilst this can be undertaken creatively, it invariably means loss of use and financial value through downcycling depriving future generations of resources.

This reveals a problem in manufacturing, namely the production of materials that impose a recycling burden on consumers, government and industries. Much of the waste diverted from landfill remains waste in perpetuity or until such time as future technologies can identify techniques to safely dispose of it. Many materials require energy to recycle so are far from carbon neutral.

Waste generation (tonnes)

	Construction and demolition						
Waste type	2011	2012	2013	2014	2015	2016	2017
Glass wastes	5,829	4,199	2,579	2,743	2,915	3,798	1,427
Metallic wastes, ferrous	137,053	107,193	123,595	113,947	124,271	91,846	145,223
Metallic wastes, mixed ferrous...	15,109	22,321	24,958	24,620	30,733	18,363	37,710
Metallic wastes, non-ferrous	10,517	13,040	15,176	11,605	12,547	12,031	16,940
Mineral waste from constructi...	1,591,493	1,259,207	1,153,104	1,281,677	1,312,342	1,408,686	1,372,415
Other mineral wastes	20,551	16,147	10,512	17,698	22,795	23,520	24,642
Plastic wastes	492	3,018	1,785	1,274	1,303	1,717	4,324
Soils	3,731,055	2,633,431	3,711,018	2,900,722	3,971,769	3,865,156	4,382,204
Waste containing PCB	3,604	249	6				
Wood wastes	34,492	94,739	101,116	98,206	81,397	7,928	30,841

Image 3: Table: Construction and demolition waste by type: 2011-17

It is vitally important that Zero Waste Scotland not only operate to reduce landfill but also work towards distinguishing and better analysing the implications of different forms of waste and manufacturers responsibilities under Polluter Pays. If taken to it's natural conclusion the Polluter Pays Principle would extend to encompass all producer responsibilities. Comparably, in the European Union, there is a Right to Repair Bill set for 2021 to extend the life and improve the recyclability of products.[30]

3.3.1 *Material Waste*

We could readily use a new definition of material waste to cover :-

(a) Those materials that are non-toxic and can be upcycled into new uses need not be viewed as waste but as food for new processes e.g., untreated timber, bricks using lime mortar.

(b) Those that cannot readily and naturally decompose and return to earth and are therefore waste in perpetuity that introduces inherent barriers to a circular economy. E.g., treated timber, plastics, and tyres.

- The embodied energy and carbon and further material waste in re-engineering
- The toxicity implications of re-engineering.

[30] "European Commissioner for the Environment Sinkevičius said that without taking such a drastic move, the bloc would be unable to reach its goal of producing zero-emissions by 2050." https://www.inputmag.com/tech/the-eu-is-planning-a-right-to-repair-bill-for-2021

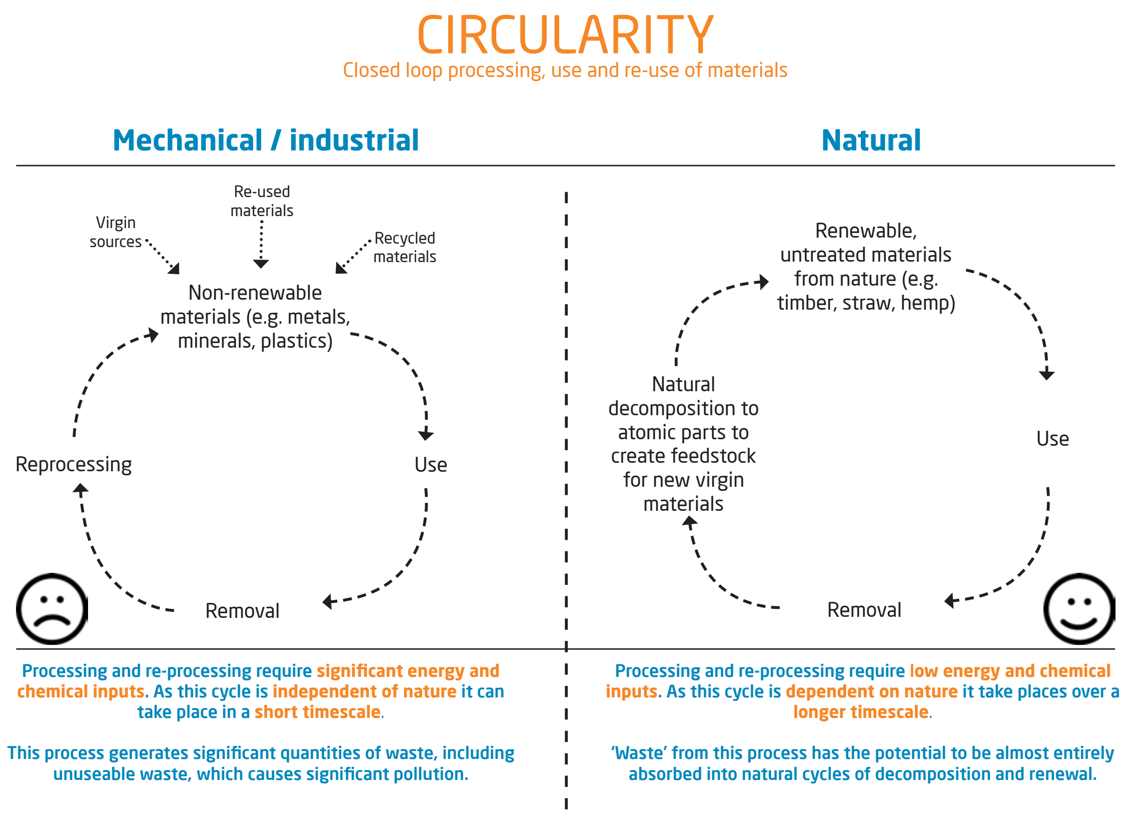

Image 4: Variation in material circularity (Source – Sam Foster)

3.4 Knowledge of The Circular Economy

The Circular Economy has long been acknowledged as a concept by environmental leading edge practice. Design for deconstruction, low impact materials, passive design and carbon sequestration have all being implemented and documented in Scotland for 20 years or more.

However, resource efficient building design is still not mainstream. The construction industry still uses 50% of Scotland's raw materials and produces 40% of the country's carbon emissions. It remains the single biggest generator of waste by bulk. Materials and services are relevant.

The concepts underpinning the Circular Economy are widely understood and resource efficient design, procurement and methods of working are widely recognised as means to achieve less waste, lower costs, and produce low carbon sustainable buildings. The knowledge now needs to be embedded across sectors such that adopting circular strategies is the norm and hence those manufactures and designers offering circular strategies can engage with the market.

3.5 New And Emerging Concepts[31]

New construction-based concepts around climate emergency have emerged and strengthened in recent years and these concepts are roughly grouped around topics.

3.5.1 Energy

- Zero carbon buildings have become more common and the concept has been further defined in terms of Net Carbon Zero. In December 2019 a cross-industry collaborative body led by the London Energy Transformation Initiative defined the logistics of Net Zero Operational Carbon.32
- The gap between regulated emissions and non-regulated emissions has been recognised as hugely significant.
- There are increasing concerns about overheating in buildings due to poor design. NB: climate data used for modelling is historic, which is likely to create problems in future unless remedied.
- Security of energy supply and potential cost increases, especially given already high levels of fuel poverty.
- The PassivHaus Standard has become more commonplace in Scotland – leading to potential mainstreaming of its key concepts:
- Very high levels of insulation
- Extremely high-performance windows with insulated frames
- Airtight building fabric
- Thermal bridge free construction (PHT, 2019)
- Scotland's electricity grid has significantly decarbonised
- There is increasing awareness of the difference between regulated energy consumption and unregulated energy consumption.

[31] Many of these concepts are addressed in Halliday S.P (2018) Sustainable Construction
[32] LETI Embodied Carbon Primer: https://b80d7a04-1c28-45e2-b904-e0715cface93.filesusr.com/ugd/252d09_869f0ce2dc8a4a65a1b87890609ede32.pdf

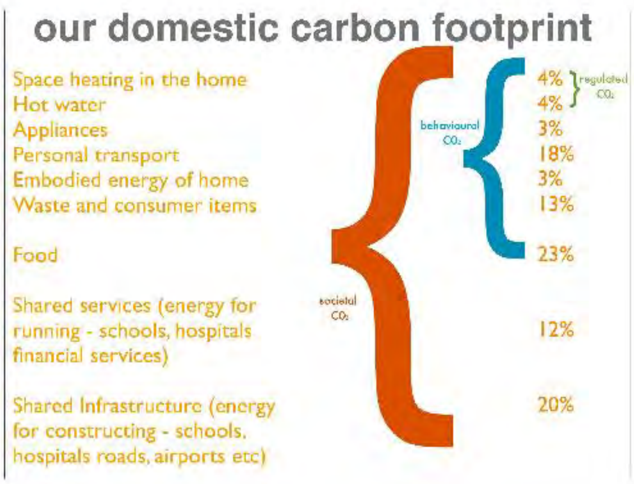

Image 5: Our domestic carbon footprint– After Craig White at Agile Design

3.5.2 Sufficiency[33]

The notion of sufficiency has become more widely discussed in relation to energy and space considerations

- **Energy sufficiency** is a state in which people's basic needs for energy services are met equitably and ecological limits are respected. This concept may be applied to both resources needed in constructing building fabrics and the energy used in supplying a building with energy. In part it is driven by the dominant use of an "energy/m^2" measure for building energy efficiency as, for example, in PassivHaus standards and the tendency for houses to be getting bigger. The aim is to start to more effectively review overall energy use / person as a more equitable standard.
- **Space Sufficiency** incorporates how effectively we utilize our existing urban context both in terms of land and buildings. The size of housing is now considered as part of the overarching view of efficiencies. This is a common design parameter in some countries e.g., space requirements as at Hunziker Areal in Zurich and implied in mixed use dense urban developments such as Vauban. (See Section 3) Based on a 35m^2 p/p, 44% of the UK population lives in under populated housing. Systems that can address this e.g. intergenerational living, may become increasingly important. Developments in adaptable buildings can also inform this approach for future developments.

3.5.3 Materials Use

- **Off-site manufacture** capacity is gradually increasing, and prefabrication is becoming more commonplace, albeit very slowly.

[33] Darby, S. and Fawcett, T. (2018) Energy sufficiency: an introduction. A concept paper for ECEEE (European Council for an Energy Efficient Economy)

- **Design for Distributed Manufacture** such as The Flying Factory and Wiki House, are promoting systems and software to put manufacture in the hands of citizens.
- **Design for layering**, modularity and deconstruction is becoming more accepted.
- **Design for Disassembly** is now well accepted.

i Design for Deconstruction, Glencoe (2001) Layering and design for disassembly: were incorporated. All layers are sequential, i.e. everything is assembled in a way that allows it to be taken apart again, either for maintenance or at the end of its life. This incorporated pioneering Easy Access Screw fixed Timber Floor Boards (see insert photo). When access is required to the service void beneath, a few screws only need be removed along the strips and the boards themselves can be removed without any damage to any component. All components can be independently repaired, tightened or replaced, and the whole can be readily re-used. The project led directly to the commissioning of research and a publication on Design for Deconstruction that looked at a number of different techniques and offered benign substitutes.

ii The BaleHaus at Bath was built as a part of an ongoing research programme to test the Modcell panel system. It was constructed from Cross-laminated timber (CLT) frames with straw bale panel infill. The first floor panels came originally from the ground floor panels of another project 'The House that Kevin Built'. The BaleHaus has iterations in 3 locations.34

i. The Triodos Bank HQ in the Netherlands is constructed from a modular demountable, wood-hybrid construction. The entire office can potentially be rebuilt in a different location without generating any waste flows.

ii. Moveable Modular Homes that can be relocated are a logical next stage. 35

- **Materials Banks** There are now numerous examples of buildings as Materials Banks and acceptance of the idea of **Material Passports.** The potential development of material passports increases the ability for effective material re-use with Building Information Modeling (BIM) supporting the development of this approach.
- **Fabric First Design** Minimising building services in favour of fabric offers space, maintenance and running cost savings in perpetuity and minimises the embodied energy in the products themselves. It s becoming better accepted as means to reduce whole life costs and waste throughout the building life cycle.
- **"Takeback" design** is increasing in particular fixtures and fittings.
- **Zero-waste lifestyle choices and shops** are becoming ever more common – particularly among environmentally literate younger generations but also reflected in commercial client aspirations for buildings.

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[34] https://www.modcell.com/projects/balehaus-at-bath/
[35] https://agile.property)

- **Materials Sourcing of pre-used materials and products** has moved from a role in high value architectural salvage to a range of creative opportunities: -

i. Salvo is a building salvage company that has been operating to retain value of materials and products in the UK since the 1980's[36]

ii. Harvestmap.org is an open platform created by Superuse Studios as a 'marketplace for professional upcyclers'. Any person or manufacturer can supply information and materials via the site. Visitors to the site can identify pools of plastics, textiles, wood, metal, chemicals and a range of other resources available to collect nearby. It also showcases publicly submitted projects that incorporate materials re-use.

iii. The approach has also been duplicated on a regional scale by Opalis who are mapping professional dealers of reused materials in Belgium.

3.5.4 Materials and Energy

- The value of **carbon sequestering materials** has developed in theory and practice with increased market penetration of straw bale, hemp, lime renders, cross laminated timber and others
- As climate awareness, and the associated drive to decarbonize has increased so too has the emphasis on reducing **embodied carbon** (often now described as **Upfront Carbon or Capital Carbon.**
- The notion of **Carbon Cycle architecture** using buildings as carbon banks is evolving. There is increased regard to biogenic materials – often agricultural by-or-waste-products - that have planned end of life use within the carbon cycle.
- **Supply chain efficiency** - a Suppliers Framework that prioritises super-local delivery based on postcode procurement to keep the carbon supply chain as short as possible – is emerging as technology develops. See - We Can Make.[37]
- Excellent and improving tools and information on **embodied/upfront energy** can facilitate and inform decisions, for example within Building Integrated Modelling (BIM). BIM software utilizes a materials section whereby each element in a construction build-up will have assigned information including embodied energy and embodied carbon. There is a plug-in to ArchiCAD called EcoDesigner STAR that can be used to calculate and export all manner of data and could assist embodied energy calculations and to material passporting.[38]

3.5.5 Housing Delivery

- **Housing as a Service** is increasingly considered as part of a closed loop approach. This puts responsibility onto the producer to ensure efficiency of resource use and operational energy. Housing Associations and housing co-operatives are well placed to take forward this approach as they are responsible in the long term for the buildings and health and well-being of tenants.

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[36] www.salvoweb.com
[37] https://kwmc.org.uk/projects/wecanmake/
[38] https://www.graphisoft.com/archicad/ecodesigner_star/

- Separating land assets from built assets.[39,40,41]
- **Location of housing** and access to low impact transport and local amenity is recognised as a fundamental aspect of a low carbon/zero waste society. Also known as Cities of Small Distances, 20 minute neighbourhoods or similar.
- **New Professionalism -** The ability to respond to the ongoing concerns is becoming an integral part of what it means to be a professional in the 21st C.
- **New Housing model**[42] The dominant housing model in Scotland for 20 years has been privately owned, detached/semi-detached, often green field site with high car dependency. It is a significant break from Scottish tradition, which followed a more European model of compact and dense low-rise 4 storey tenements under collective ownership. The model has come under increasing pressure as fewer and fewer local facilities such as shops, dental, health, schools and play areas are now provided. This increases dependence on cars (even electric cars require electric resources) and undermines the energy benefits of decarbonisation of the grid and the improvement in building regulations over time. This requires policy and regulation to recognise the need for circularity of cities and the contemporary ideas of placemaking and 1 planet living.

3.5.6 Technology Choices

- Regulations now favour some local renewable energy generation for new housing. This starts to raise important questions about the comparison of grid versus locally generated electricity or heat as the Scottish electricity grid has been significantly decarbonised. The CO2 payback of a PV cell manufactured in China with very high CO_2 emissions may be unjustifiable compared to grid supplied off shore wind energy.
- Net Zero Energy Building (NZEB) based on local sources of renewable sources is an increasingly common aspiration. The above concerns require clarification to prevent perverse policy implications.
- **Water economies** are now increasingly common in housing with low flush toilets the norm, low flow taps, aerators and eco-button technology applied by some HA providers.
- **LED's** are now established as an affordable resource efficient technology with light quality compatible with many needs and requirements.

3.5.7 Existing Buildings

- **Refurbishment**- The potential for is enormous. Whilst refurbishment is outside the scope of this project, the potential is enormous and simple improvements can vastly improve performance of existing buildings making this "low hanging fruit" a priority.[43] There are numerous opportunities to address waste.

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[39] https://library.croneri.co.uk/cch_uk/btr/509-250
[40] https://kwmc.org.uk/projects/wecanmake/
[41] Community Right to Buy legislation - https://dtascommunityownership.org.uk/community/community-rights/land-reform-act/land-further-sustainable-development
[42] https://www.ucl.ac.uk/news/2020/jan/new-housing-design-england-overwhelmingly-mediocre-or-poor
[43] https://www.gov.scot/publications/housing-statistics-scotland-2019-key-trends-summary/

- **Retrofit for resource efficiency -** ReHab Carbon was part of Retrofit for the future. It is a design approach that integrates behaviour-led design with sustainable technologies and creative new development models to maximise the potential of our existing *buildings* and landscapes while addressing their *carbon* habit.[44]
- **Enerphit -** is a refurbishment Standard based on the PassivHaus methodology.[45]
- **EnergieSprong**[46] is a market-driven approach to funding and delivering attractive 'whole-house ' refurbishment with guaranteed net zero performance. It originated in the Netherlands.

3.6 Benchmarking

There are schemes available at all stage of the design, planning and construction process and during a building's life - that encourage benchmarking and can assist in delivering different aspect of the circular economy principles in housing.

3.6.1 Overall Appraisal

- UN Sustainable Development Goals
- Eco-Footprinting
- 1 planet living - 2000w house
- Living Building Challenge

3.6.2 Biodiversity

- Design With Nature,
- Building Biology

3.6.3 Materials Choices

- EU Audits
- Green Building Data base
- One Click
- Red list

3.6.4 Zero Waste - Products and services

- C2C
- Nordic Swan
- Superuse Studios – harvest map

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https://www.gov.scot/publications/housing-statistics-conversions-and-demolitions/
[44] https://www.white-design.com/architecture/retrofit/
[45] https://europhit.eu/content/enerphit
[46] The EnergieSprong Model is a developer-guaranteed, Zero Energy retrofit. www.energiesprong.uk/

3.6.5 Energy

- RIBA Climate Challenge,
- London Energy Transformation Initiative (LETI)
- AECB Standards
- BREEAM
- Code 4 Sustainable Homes – redundant but still useful
- LEED Passive House
- PassivHaus Plus
- PassivHaus Premium
- Enerphit
- EnergieSprong

3.6.6 Stakeholder Issues/ Controls and Benchmarking

3.6.6.1 Architects

- RIAS Accreditation
- New Professionalism

3.6.6.2 Specifier

- Embodied energy calculations

3.6.6.3 Manufacturers

- Regulate Waste off site
- Minimise /Tax Future liability
- Polluter Pays – extended producer responsibility

3.6.6.4 Developer

- Fabric/massing/location/ upfront energy of materials /future proofing of materials

3.6.6.5 Constructors

- Site practice
- CCS, CEEQUAL
- SWMP
- Details – (AT/Thermal imaging)
- There are no schemes for quality assurance for:

iv. Builders/Trades (required through training Schemes)

v. Developers (required by planning)

4 Towards a Brief for Resource Efficient Housing 2020

4.1 Background

Designing and building single, detached new houses at low density and locating them on brown or greenfield sites accessible only by car, and with few surrounding public amenities, reflects an out-dated but still prevalent volume house building concept. It is clearly far less resource-efficient than designing and building a group of interconnected houses at medium density in an area well served by public transport and a range of social amenity and infrastructure.

There are already enough existing houses in Scotland to meet demand.[47] However, the challenges of empty, second and holiday home ownership and migration from rural areas to urban centres, contribute to a problem of affordable, available houses not being located where people want to live. The Scottish Government has a stated ambition to reverse rural depopulation in Scotland and this inevitably raises the question of whether it is the houses or the people that are in the wrong place, and the extent to which current policy on housing is abetting rural depopulation.[48]

A vitally important aspect in resource efficiency, which should not be outwith the framework of this report, is tackling refurbishment. Perhaps the single biggest issue facing the construction industry is the urgent need to refurbish and re-use existing buildings so that demolition can be avoided and the need for new build can be reduced. There is an argument that refurbishment of almost the entire existing housing stock offers potentially significant savings in embodied/upfront greenhouse gas emissions compared to demolition and new-build.[49,50] It is most certainly low hanging fruit that would be best tackled early.

Key to achieving necessary radical resource economies will be a move towards the idea of *sufficiency*, i.e. how much is enough – be that for energy, food, space, water, work, comfort and many other aspects of a fulfilling life.[51] A starting point for that will be a clear understanding of our global allowances for each of these.

4.2 Innovation

If we are to continue to experiment with housing and construction ideas it is essential that we move away from abstract 'pilot projects' to fully inhabited, living environments that are integrated into their communities and contribute positively to daily life at all levels. The recent tendency to Innovation Parks

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[47] Based on ~100,000 empty and second homes (https://blog.nrscotland.gov.uk/2017/06/14/estimating-the-number-of-homes-in-scotland/), average occupancy of 2.2 people per household (https://scotlandscensus.gov.uk/) and ~200,000 people on waiting lists for housing (https://theferret.scot/200000-people-waiting-list-affordable-housing/)

[48] Increasing the population of rural areas of Scotland is included as one of four outcomes for the National Planning Framework.: https://www.gov.scot/publications/national-planning-framework-3/

[49] https://edgeenvironment.com/new-build-vs-refurb-life-cycle-answer/, https://historicengland.org.uk/content/heritage-counts/pub/2019/hc2019-re-use-recycle-to-reduce-carbon/,

[50] http://www.superhomes.org.uk/wp-content/uploads/2012/06/Lifetime_CO2_Emissions-Retrofit-vs-New-Build_2011.pdf

[51] Space- https://www2.gov.scot/resource/buildingstandards/2017Domestic/chunks/ch04s12.html

for demonstrating new ideas has exposed them as single specimens of disconnected ideas, requiring large quantities of materials and energy to create, and incapable of developing the rich, diverse and climate-emergency ready communities required today. Buildings on demonstration sites (such as at BRE Watford and BRE Ravenscraig), most of which are unlived in and all of which are new-build, are detached - not just physically - from each other, but from the industries and society they hope to positively shape.[52,53,54]

There are numerous examples of how integration has succeeded in practice.

Interestingly a community such as Tombreck on Tayside has been building housing using innovative techniques for many years – including hemp, hempcrete, straw and roundpole, This has been in direct response to local need and in pursuit of a sustainable growing affordable community. This demonstration in action has far reaching influence through the incorporation of training days, volunteering and self-build experiences.

4.3 Sources and Types of Waste

Waste is a catastrophic invention generated solely by human activity. It results in pollution, poverty, ill health and climate change. Reducing waste relies on a clear understanding of where it is generated (the *source*) and what *types* of waste are generated so that action can be taken to prevent it happening. Waste types include:

- Opportunity
- Land
- Space
- Money
- Time
- Energy
- Effort
- Knowledge
- Materials
- Water

Buildings generally have a life that spans five basic stages: 1) pre-design; 2) design; 3) construction; 4) occupation and maintenance; and 5) deconstruction. Each stage is a potential source of inefficiency, creating different types, and amounts, of waste.

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[52] Kalkbreite. (6 mins) https://youtu.be/MkHFeb8tkCU
[53] Tubingen (18 mins) https://www.youtube.com/watch?v=wSfFF0Lx4cw
[54] Scotland's Housing – More than Just Numbers (7 mins) https://youtu.be/6Z6Rc7WSyzQ

4.3.1 Waste through Pre-design

The decisions made at pre-design stage will 'lock in' the likelihood of generating waste and pollution throughout the lifespan of an entire project. Poor decisions at this stage are impossible to 'fix' through good housing design and construction quality.

4.3.1.1 **Distance between places:** Since the 1930s we have been conditioned through successive planning regimes to believe that 'housing' should be separate from 'work', 'industry', 'education' and 'recreation'. As a result we have moved from villages, towns and cities as diverse, highly integrated, fully-occupied systems with a series of distinct cultural and social focal points to fragmented, mono-functional 'zones', each of which experience near-zero occupation at certain times of day.

The consequence of this form of planning is that we now consider our dependency on travelling significant distances between these, by car, bus, train or even aeroplane, as 'normal'. As well as consuming a large proportion of our time and reducing our sense of identity and belonging, this travel causes stress and illness and generates enormous quantities of pollution and greenhouse gases and consequent climate change. The American "Downtown" is a clear example, as is the creation of new towns such as Cumbernauld.

"In Cumbernauld less than 18% use public transport for their daily commute, compared with 36% in Glasgow. The 26% of commuters in Glasgow traveling under two kilometres per day by public transport, have an individual carbon footprint of less than 0.5 kg. The Cumbernauld commuter traveling up to 80 km round trip by car, will have a footprint of more than 20 kg. This results in Cumbernauld, a town with a population of circa 35,000 having a larger carbon footprint for the daily commute than the entire City of Glasgow with its 650,000 inhabitants. Such satellite communities are also at the mercy of future oil price hikes, and the population of these new towns is already starting to fall, more likely than not, due to such crude economic drivers. Urban form and location can directly affect the socio-economic base, which invariably has a direct and immediate impact on public health and wellbeing. The family budget may not stretch to the "luxury" of fresh fruit and veg if it has been exhausted on travel." [55]

These pre-design decisions are automatically pre-determined to generate waste in the following ways:

- Wasted **opportunity** to counteract the impacts of mono-functional zoning ("*imagine we decided to do something* better"*;*
- Waste of **land** for unnecessary roads, parking and vehicle infrastructure, as well as low density housing in suburbs and mono-functional buildings ("*imagine we decided to intentionally use less land, by increasing housing density and closely integrating this with places of work, education, food production and play);*
- Waste of **time** spent travelling between places – particularly home and work ("*imagine a maximum commute of 15 minutes walk for everyone")*;
- Waste of **energy** constructing the infrastructure and then travelling between its nodes ("*imagine how much less pollution would be created")*;

[55] https://strathprints.strath.ac.uk/37417/

- Waste of **money**, on its design, construction, maintenance and associated travel ("*imagine how that money could be used for better purposes")*;
- Waste of **materials** in the construction, maintenance and ultimate demolition/disposal of the infrastructure ("*imagine how much less damage would be done from not excavating and 'winning' construction materials")*
- Waste of **water**, huge quantities of which are embedded in the manufacture of materials, construction processes and in building use.[56]

Each aspect described below will result in the creation of *at least* one type, and often many, types of waste from the above list.

4.3.1.2 **Home ownership as wealth accumulation:** As private home ownership and house prices increase people tend to move more frequently. This can be for a number of reasons. Home owners may wish to up size because of a growing family or down-size to realise the equity in their house;[57] to move to a school catchment area or to a higher-value area due to a perceived level of affluence. People may be forced to move further afield due to high house prices and/or a lack of affordable rental housing. This is exacerbated by schemes such as the Right to Buy (which still exists in parts of England but was abolished in Scotland in 2016) and by poor provision of social infrastructure and public transport. Moving house is frequently linked to renewal of interior decoration and replacement **of kitchen and** bathroom fittings –for cosmetic or functional reasons – leading to significant generation of waste.

4.3.1.3 **Finance:** Houses for private sale by volume house building companies can include more than 30% profit.[58] The disparity between cost and value is expected to increase.[59] The profit distributed by volume house builders goes to shareholders, many of whom are based overseas, which removes this cash from the UK economy. Other shareholders are likely to invest dividends in other stock, which also has the effect of removing circulating cash from the economy.[60]

4.3.2 Waste through Design[61]

In addition to waste generated from the construction process, most building projects use significantly more resources than they might. Many decisions made at design stage will have an effect on the type and quantity of waste generated on any project. These decisions can have positive effects if the brief is ambitious and the implications of getting them right (and wrong!) are clearly understood by the client and all members of the design team. Setting targets for elimination, or minimisation, of waste is an essential first step at the design stage.

4.3.2.1 **Design lifespan:** Much of the 1950s and 1960s housing stock and tower blocks have been demolished over the last twenty years and standard design life for housing remains in principal at 60 years. At current demolition rates, however, the housing renewal period in Scotland is 2,100 years

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[56] Water Efficiency the contribution of construction products 2015 Construction Products Association
[57] https://www.independent.co.uk/property/how-often-do-people-move-house-8969393.html
[58] https://www.ourcity.london/issues/viability/house_builders_profits/
[59] https://www.thisismoney.co.uk/money/news/article-8032805/Housebuilder-dividends-soar-1billion.html
[60] Kennedy M (1987) Interest and Inflation Free *Money*, Creating an Exchange Medium that Works for Everybody and Protects the Earth
[61] https://www.zerowastescotland.org.uk/construction/design-out-waste

suggesting that there is a baseline of housing which has much longer lifetime. Much of it will be unsuitable for current conditions.62 To prevent this waste requires a number of interventions including refurbishment. We must significantly increase the design lifespan of our houses, make them climate and demographically robust, maintainable and flexible, whilst also accepting that they will need to be replaced at some point.

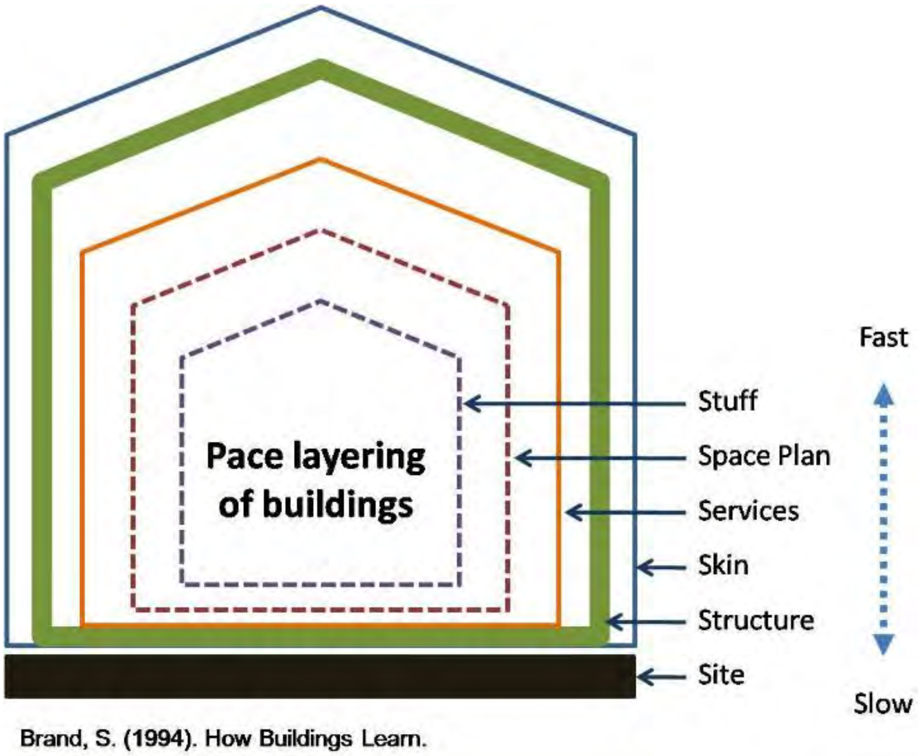

Image 6: Shearing Layers of Change after Brand

4.3.2.2 **How we fix things together and take them apart, and what we do with them:** Current design and construction practice pays very little attention to the need to be able to disassemble components in the future, either for maintenance or at the end of their current use. Similarly, typical construction methods involve multiple layers (sometimes as many as 11) in their make-up, each layer offering the potential for poor workmanship and generation of waste. As a consequence significant volumes of construction waste are generated during construction, maintenance and end-of-life disassembly. As noted earlier the volume of waste from construction sites in Scotland is increasing. The industry needs to reach a state of balance where a fixed volume of benign, low overall embodied (upfront and reprocessing) energy material is constantly cycling - in a cradle to cradle manner - through a process of use – disassembly – reprocessing – re-use – disassembly etc.

[62] Personal communication with Dr. Richard Atkins

4.3.2.3 **Prefabrication:** Prefabrication has evolved. Many volume housebuilders now use prefabricated floors, walls and roofs as a matter of course in an effort to increase speed, reduce cost and increase profit. This is largely done in a panellised format as transport of panels maximises the quantity of components being transported at a time, compared to now outdated pods, with wasted volume.

4.3.2.4 **Building Information Modelling (BIM) and prefabrication:** the increasing use of BIM is highlighting the potential to reduce waste on site by identifying potential issues, or 'clashes', for example between structural elements and building services components.63 When combined with prefabrication of construction components, such as floor, wall and roof elements, it is possible to significantly reduce waste.

4.3.2.5 **Density and massing:** The prevalent housing model in Scotland is controlled by volume housebuilders' 'estates' predominantly made up of detached houses with a low density of between 15-30 dwellings per hectare (dph). Traditional terraced, low-rise housing and flats up to four storeys can deliver densities of over 100dph. Detached houses have significantly more external wall and roof area – all losing heat when it's cold outside and costing more money to build – than terraced and multi-storey houses and flats. For any given number of multiple houses and flats it is more land-efficient, material-efficient and energy-efficient to build terraces and multi-storey than to construct detached individual units. 64

4.3.2.6 **Accessibility:** Private, detached houses are typically arranged around a predetermined road layout, irrespective of orientation, prevailing wind and topography, with parking provided for each house and flat. Car travel is prioritised over walking and cycling, encouraging vehicle use and resulting in increased air and ground pollution and greenhouse gas emissions. Pedestrian safety is compromised and the outlook from houses is disfigured by tarmac and vehicles. Play is relegated to generic play equipment in a distant corner overseen by no-one and requiring CCTV and additional lighting, rather than being integral to housing layouts.

4.3.2.7 **Top soil:** Most new housing development involves disruption of complex existing biodiversity networks and the movement of large volumes of topsoil and subsoil. This soil can be rich in microbes, insects and worms and is known to store large amounts of CO_2. As soil is relocated and compacted in temporary storage piles on site it can decompose, releasing some of this CO_2 to atmosphere. Soil movement can therefore make a large contribution to greenhouse gas emissions from projects.65

4.3.2.8 **Green/blue space:** Green space around housing is rarely used to grow food for residents. Replacement of permeable ground with large areas of impermeable road, parking and roof surfaces increases flood risk– particularly as car ownership increases. This is often mitigated by investment in concrete and plastic artificial drainage, either to temporary holding areas 'Sustainable Urban Drainage Systems ('SUDS') or to mains drainage systems and watercourses. All require regular maintenance and the latter channel large volumes of water 'away' to become someone else's problem. It is almost all hidden from sight below ground, removing from the public realm the contribution to health and well-

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[63] https://digital.lib.washington.edu/researchworks/bitstream/handle/1773/38546/Wu_washington_0250O_16888.pdf?sequence=1

[64] *Image of form factor* https://www.thefifthestate.com.au/innovation/design/how-changing-building-shape-and-form-can-slash-energy-use/)

[65] https://repository.rothamsted.ac.uk/item/8678q/model-estimates-of-co2-emissions-from-soil-in-response-to-global-warming

being that water and landscape brings. In Berlin & Malmo there is a required Biotope factor66 – a percentage (up to 30%) of the area of built development that must be dedicated to blue and green landscape.

4.3.2.9 **Orientation, daylighting and sunlight:** By laying out identical houses to face access roads it is inevitable that many will receive sunshine at the 'wrong' time of day. Sitting rooms, for example, may face north instead of south, leading to deficiencies in daylight that can contribute to depression and give rise to excessive costs for compensatory artificial lighting. Many 'habitable' rooms in new houses (such as sitting rooms, bedrooms and kitchens) are often designed with the smallest windows necessary to comply with building regulations. These reduce exposure to daylight, with similar adverse impacts on health and energy, and can be exacerbated by overshading from neighbouring buildings. Toilets may face south, taking up precious space on the warmest side of the house for a room that is perhaps least used. Bedrooms may face west instead of east, leading to overheating and contributing to ill health. Overheating is an increasingly common issue in new houses, caused by poor design and lack of adequate shading. Whether for heating, cooling or lighting, inappropriate orientation has implications for increased energy use and corresponding greenhouse gas emissions.

Image 7: Modern Estate – Photo: David Seel

4.3.2.10 **Shelter:** Buildings can benefit enormously from the shelter offered by appropriately positioned trees, tall plants, other buildings and topographical features such knolls and dips. Removing or altering these, or not having any in place, increases the exposure of buildings to wind, increases heat loss, energy use and hence greenhouse gas emissions.. Detached houses, with greater surface area than terraced and multi-storey houses and flats, will suffer most from lack of shelter.

4.3.2.11 **Size and future flexibility**: Housing in the UK is the smallest in Europe and occupants in more than 6% of social rented housing in England suffer from overcrowding.67 A combination of this and the high

[66] [66] Biotope Concept https://www.berlin.de/senuvk/umwelt/landschaftsplanung/bff/index_en.shtml

prevalence of owner occupation in the UK lead to large numbers of loft conversions and extensions. These processes inevitably generate waste. This is often worsened when buildings have been constructed to minimum standards and without regard to future conversion. An example of this is the use of ‘fink trusses’ for the roofs of newbuild houses, which have inadequate strength to be altered to create habitable rooms. Home working is becoming increasingly popular, particularly with increases in internet speeds. Small homes, unless integrated into mixed use development and shared facilities, can place constraints on the potential for this.

4.3.2.12 **Operational energy:** A significant proportion of housing in Scotland is designed to achieve minimum building regulations for operational energy use and CO2 emissions – the lowest possible standard allowable in law.68 Less than optimal construction processes means that most fall short of the design and therefore fail to achieve even this legal standard. Houses are not routinely tested for performance or occupant comfort, effectively preventing remedial work from taking place. This is the well-documented ‘performance gap’. It results in excessive energy use, fuel poverty, occupant discomfort and consequent greenhouse gas emissions.

4.3.2.13 **Recycling:** Recycling is often touted as a way of reducing the environmental impact of materials. However this often fails to consider the energy and toxicity associated with their reprocessing. As a principle, it is better to avoid the use of toxic materials than to seek to justify it as recyclable.

4.3.2.14 **Chemical impact on health:** Many houses are located and orientated so as to expose occupants to air (and noise) pollution from traffic. This is known to be harmful to health with the EU estimating nearly 500,000 early deaths due to traffic pollution.69 In addition to this most mainstream construction materials and finishes are typically synthetic and chemical-rich in nature. Occupants often move in to their homes when they have been freshly decorated and have a heavy chemical load and generally without guidance on how to operate heating systems and ventilators for best efficiency and health. They also unwittingly further decorate and furnish them with items that contribute to the chemical load – such as new furniture - and add to this toxic cocktail with cleaning products, artificial fragrances, and cosmetics. More than 55,000,000 chemicals substances exist. There is no accurate record of the number that are used in construction materials, finishes, furnishings and consumables but it is recorded that fewer than 900 have been tested for human toxicity.70 Many are known to be toxic, including chlorobenzene (used in paints and adhesives), formaldehyde (used in adhesives for wood products such as OSB and in insulation), phthalates (used as softeners in plastic products) and isocyanates (used in common foam insulation). Most flame retardants contain the hazardous chemical element bromine, and some studies show that they increase amounts of carbon monoxide and hydrogen cyanide released during fires. The risk to health can potentially do more harm than good in a fire, with many victims dying from chemical toxicity rather than smoke inhalation.71

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[67] https://www.birmingham.ac.uk/Documents/college-social-sciences/social-policy/SPSW/Housing/2016/good-housing-better-health-2016.pdf
[68] Housing Associations tend to perform better than private builders.
[69] https://www.bbc.co.uk/news/world-europe-46017339
[70] http://www.props.eric-hart.com/safety/so-many-chemicals-in-the-world/
[71] https://www.niehs.nih.gov/health/topics/agents/flame_retardants/index.cfm

A 2017 survey found that people in the UK spend more than 92% of their time inside buildings72. This figure can be even higher – most of it spent at home – for the very young and the elderly. While humans and animals of all ages can be affected by these chemicals it is these same age groups, whose respiratory and physiological systems are in development or naturally weakened by age, that are most likely to be affected. Specification of materials with the potential to cause ill-health ultimately results in entirely avoidable additional costs for health and social care services.

4.3.2.15 **Material selection:** With the exception of building with local earth or possibly green wood or straw, the production of almost all construction materials involves the use of energy and transport, resulting in greenhouse gas emissions and pollution. Common *mineral-based* construction materials such as cement, sand, aggregates and stone, and *petrochemical-based* construction materials including most mainstream insulation, membranes, paints and floor finishes involve highly damaging extraction processes that cause pollution and generate waste. The harvesting of most tropical hardwood and overseas timber has similar destructive impacts. In addition to high embodied/upfront energy and CO_2, all can result in habitat and species loss, contributing to loss of biodiversity. Many construction materials exist which have much smaller impacts. Most of these are *plant-based*, including timber from UK and European sources (for structure, insulation, cladding and joinery), and many plant crops including straw, hemp and jute (for structure, insulation and sheathing). The use of these also has many positive impacts on occupant health, reducing demands on healthcare services. [73]

4.3.2.16 **Digital connection and data, human interaction:** Our homes are becoming increasingly connected to the internet, transferring data from 'smart' appliances, lighting and heating systems and audio devices to data centres all over the world. We can, if we wish, order food from a supermarket simply by using our smartphones or asking a smart home device. At a larger scale, the design process is being used to create a 'digital twin' of our houses, allowing information records to be assigned to every single component and – theoretically – assisting in their maintenance, repair and re-use. While this has clear potential benefits for reducing waste it also has two major ramifications:

1. It contributes to the growing energy demand of the internet[74,75] and associated greenhouse gas emissions,
2. It removes a layer of potential human interaction, for example through the process of visiting a shop to buy groceries. While the latter is difficult to quantify in terms of waste generation, reduced social interaction can lead to isolation and physical and mental health issues – resulting in unnecessary additional costs for health and social care services.

4.3.2.17 **POE/BPE targets:** It is essential that performance and comfort targets are set at the design stage so that clients, designers and occupants can be confident that they have satisfied the brief, and so that any mistakes can be learned from and avoided in future. These targets must include waste, with a view to eliminating it entirely.

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[72] https://road.cc/content/news/217728-brits-spend-92-all-their-time-indoors

[73] Brown, M (2016). Futurestorative 40% of any nation's health care costs are directly attributable to its built environment.

[74] https://www.bbc.com/future/article/20200305-why-your-internet-habits-are-not-as-clean-as-you-think

[75] https://fortune.com/2019/09/18/internet-cloud-server-data-center-energy-consumption-renewable-coal/

4.3.3 *Waste through Construction*

Other than the demolition phase, most physical waste from conventional projects is generated during their construction. This occurs for a limited number of reasons:

4.3.3.1 **Over-ordering:** It is common practice to add a percentage to orders to allow for 'wastage'. Through poor measurement over-ordering results in unused materials and components. The opposite – under-ordering – results in additional transport needs;

4.3.3.2 **Workmanship and procurement:** Most projects include numerous specification clauses setting out levels of construction quality to be reached on site. Despite these, their achievement in practice relies on a combination of a desire by tradespeople to do a good job and regular inspection by others. Procurement routes such as Design & Build or Contract Management tend to prioritise cost and speed over quality. They remove the ability for quality to be regularly monitored – and rectified if substandard – and encourage subcontracting of work packages for the lowest price. This can result in poor workmanship and lead to additional waste generation;

4.3.3.3 **Site-built vs. prefabrication:** An increasing proportion of Scottish construction involves the use of prefabricated timber frames, both as uninsulated 'kits' and pre-insulated panels. Factory prefabrication can reduce material waste by an estimated 90% and time on site can be reduced by 50-60%.[76]

4.3.3.4 **Use of prefabricated construction elements** has the potential to drastically reduce waste compared to site-building;[77]

4.3.3.5 **Not following construction drawings:** waste occurs when materials and components have to be taken down and re-built due to construction workers not following construction drawings. If not easily disassembled and re-used these components will become waste.

4.3.4 *Waste through occupation and maintenance*

At the point when buildings are occupied it is possible to minimise further generation of waste by ensuring occupants are clearly shown how best to look after and operate them.

4.3.4.1 **Lack of guidance for occupants on system control:** overheating and over-ventilating can result in wasteful energy use. Under-heating and under-ventilating can result in condensation and mould, accelerating deterioration of internal finishes and furnishings, reducing their lifespan and potential for re-use in the future. The same conditions can also cause ill-health, impacting on health and social care services.

4.3.4.2 **Maintenance cycles:** It is widely known that 'prevention is better than cure' when it comes to building maintenance, and that simple measures such as keeping gutters free flowing can prevent much more costly repairs – and the creation of waste – from damage caused by water ingress. Despite this

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[76] Designed, Sealed, Delivered: This report focuses entirely on off-site manufacture in housing.https://www.london.gov.uk/sites/default/files/london_assembly_osm_report_0817.pdf
[77] https://www.tandfonline.com/doi/abs/10.1080/15623599.2014.899129

knowledge, 57% of all of Scotland's homes require maintenance of critical elements. [78] The use of high quality building materials and components, assembled in a way that allows them to be maintained, repaired and – if necessary – replaced, is essential. Enabling this to happen in practice relies on appropriate decisions being made at the design and construction stages.

4.3.5 Waste through deconstruction

Together with the construction stage this part of the lifespan of a building represents the period of greatest potential waste generation. Mineral wastes, including brick, block and concrete, tend to be crushed for re-use as low-grade aggregate, while timber waste is either incinerated or pulped for use in low-grade sheathing boards. All of these result in alternative waste in the form of significant associated energy use and pollution.

The ability to effectively separate and re-use components at their original – or higher – value relies on enabling decisions being made at design stage. Bricks cannot be easily re-used, for example, if laid in cement mortar but can be re-used if laid in lime mortar; similarly timber will generally be downcycled if treated and glued, but can be re-used if screwed or nailed together.

4.3.6 Summary

Combining these ideas, the proposal for our brief is a single project involving the design and construction of a number of new houses and refurbishment of *the same number* of existing houses, located within an existing settlement with public transport connections, social infrastructure and employment opportunities integrated at the outset. There are many projects that demonstrate aspects of what is required.

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[78] https://www.befs.org.uk/scotlands-historic-environment/facts-figures/

4.4 Contemporary Concepts and Built Exemplars

4.4.1 PassivHaus

- Goldsmith Street - Mikhail Riches with Cathy Hawley - PassivHaus Social
- Callaugtons Ash - Architype – PassivHaus Social Housing
- Bristol Passiv Haus Plus - 2018
- Fulmodeston - Barney Affordable Housing 2014 - Mole Architects
- Larch & Lime House - Bere Architects
- Vorarlberg – Austria
- Plummerswood, Scottish Borders 2012
- Future Build Programme, Norway 2010-20

4.4.2 Eco- Sufficiency – planetary limits and space optimization

- More Than Housing – Hunziker Areal - 2000-watt society –
- Kalkbreite

4.4.3 Activ Hus - PassivHaus alternative

- Hurdal Eco-village, Hurdal, Norway

4.4.4 Plus Energy

- Vauban
- Future Build Plus+ Programme, Norway – 2020

4.4.5 Offsite Construction

- Zed Pods
- Tam/Modcell
- Larch House, Makar
- Brettstapel
- Acharacle School Scotland 2009
- Plummerswood House Scottish Borders 2012

4.4.6 Design for Deconstruction

- Glencoe Visitor Management Facility – Design for deconstruction 2001
- Plummerswood, Scottish Borders 2012
- Acharacle Primary School 2009

4.4.7 Low Impact Materials

- Dunning
- Glentress
- The Piggery

- Tombreck
- Brighton Waste House - Duncan Baker-Brown
- The Enterprise Centre - Architype
- Tam/Modcell
- Kamitkatz Public House - Zero Waste
- Cork House - Matthew Barnett Howland
- Studio Fiskavaig Self-build, Isle of Skye - Architects Alan Dickson and Gill Smith
- Reused Containers/ Reach Homes

4.4.8 Co-Housing

- LILAC
- Lancaster Co-housing
- Marmalade Lane Co-housing
- OWCH (Older Women's Co-Housing)
- Copper lane - Henley Halebrown
- Startblok Riekerhaven – Amsterdam

4.4.9 Biotope Factor

- Malmo
- Spreefeld

4.4.10 Extended Building Lifespan

- Acharacle School Scotland 2009
- Plummerswood Scottish Borders 2012

4.4.11 Net zero

- Ullsholtveien 31 - Future Build Programme, Norway - 2017

4.4.12 Other

- Haus and TEK 10 standard
- Granby

4.4.13 Projects in progress

- Eildon HA
- Kingdom HA

5 Selection of Relevant Case Studies

5.1 Net Exporter - Plusenergie Houses, Vauban, Freiburg (2005)

Architects: Various

Image 8: Vauban Plus Energy Housing – Photo: Halliday

Schlierberg is a 59 home PlusEnergy housing community in the Vauban area of Freiburg, Germany often referred to as the Solar Settlement. The scheme has been described as the first housing scheme where the houses produce a positive energy balance. They are therefore considered emissions-free or CO_2 neutral. As of 2011, the homes had more than 8 years of full occupancy. Each produced surplus energy every year from which the owners of the houses benefitted. The houses are timber framed. PlusEnergy is a concept developed by Rolf Disch based around low energy and passive solar design with localised renewable energy production (from solar panels) to produce a positive energy balance measured over the course of a year. The concept can therefore be seen as a forerunner of the new PassivHaus Plus standard.

The Solar Settlement as well as other plus energy and PassivHaus standard houses in the Vauban area was built as an exemplar of a sustainable community. There are over 5000 inhabitants and a mandatory low energy standard of 65 kWh/m² applies for both commercial and residential buildings. Every building has solar panels on its roof so that over 65% of the energy used in the district is generated by photovoltaic panels. Vauban also contains the first multi-family PassivHaus apartment block in Germany. Vauban was created through cooperative decision making. It has become a model of holistic environmental planning and eco-friendly living. Space for resident designed houses was allocated alongside traditional developer procured housing and locally inspired initiatives for green technologies in buildings have been promoted.

Vauban is designed around a medium density approach to sustainable planning and consists of mostly three or four storey residential buildings interspersed with parks, trees and open green spaces. The population density is 122 persons/ha. Ground floor space is dedicated mainly for service functions in order to provide a mixed-use tight urban grain with readily accessible local service to all residents of the neighbourhood. This tight urban grain supports sustainable transport patterns but also addresses issues around ‘Energy Sufficiency’ discussed later in this report.

The district is planned around green transportation - pedestrian and bike paths connect every home within walking distance of a tram stop. Whole streets are free of parking spaces. There are two car parks on the edge of the district but 70% do not use a car. A district heating grid provides heat and power with 80% generated by a woodchip powered generator.

Using circular economy principles, organic waste is treated in an anaerobic digester, biogas used for cooking energy and grey water is cleaned in biofilm plants and returned to the water cycle. The neighbourhood has been analysed with respect to buildings, infrastructure, electricity supply, heat supply, water and waste, traffic and private consumption with a full life-cycle perspective.

5.1.1 References

i. Medved, P. (2017) Leading sustainable neighbourhoods in Europe: Exploring the key principles and processes, Urbanni izziv. Vol. 28. No.1. pp 107-121

ii. Thorpe, D. https://www.smartcitiesdive.com/ex/sustainablecitiescollective/words-most-successful-model-sustainable-urban-development/229316/

5.2 Low Impact Materials – TAM by Agile Homes (2018)

Architects: White Design

Tam is a response to the housing crisis that provides a typology of housing that:

- does not require the acquisition of land;
- utilises Modern Methods of Construction;
- is low-carbon in energy performance;
- has a low-embodied carbon footprint;
- provides a carbon capture and storage solution using renewable materials;
- uses the circular economy concept of co-products and by-products of the agricultural sector;
- is affordable;
- complies with the Caravan Act to allow relocation;

- can be asset financed.

Image 9: TAM by Agile Homes

By converting the capital costs of land acquisition into a low or zero revenue cost, up to 40% of the development costs of building homes are removed. There is no requirement for conventional concrete foundations and slab, instead pads and screw piles can be used reducing materials use and hence emissions and leaving the land below the TAM available for future re-use.

The super structure of the Tam is prefabricated panels made entirely of straw and timber. The main structural framing components of the panels are timber while sheathing boards for each panel are made of Compressed Straw Board. The use of chopped straw, as opposed to bales, allows variable width panels to be designed to meet target U-values. The system was certified with the PassivHaus Institute in 2015 as a whole house building system. The linings are plasterboard free (a semi hazardous waste material), instead Fermacell is used. Fermacell is specified because it uses recycled paper gypsum and water in manufacture and does not use any glue products, it removes the need for wet trade plastering and has impact resistance far in excess of plasterboard reducing maintenance and extending life to first re-fit.

The build system supports PassivHaus levels of airtightness. This airtightness combined with triple glazing, mechanical ventilation heat recovery (MVHR) and LED lighting throughout means the total energy consumption is 100 kWh/m^2/annum without the need for renewable energy technology. The

application of PV's would reduce this further.

Image 10: TAM by Agile Homes – plan and section

The building has an inherently low carbon footprint through the use of low embodied carbon materials. The windows, for example are specified because the aluminium sashes are smelted using energy from renewable hydro electric sources only.

The use of a predominantly renewable material palette has the additional benefit of carbon capture. The timber and straw captured CO_2 as it grew, through photosynthesis. The timber captures 742kg CO_2/m3 and the straw 1.42 kgCO_2 / kg. The total CO_2 capture for a 37m^2 TAM is 27 tonnes or 730 kg per m^2 of GIFA.

The costs of a one bedroom TAM as a shell ready for fit out is £64,990 and fully fitted is £77,990. A two bedroom 50 m^2 shell is £84,990, fitted out £98,990. For each site there are typical location costs of £10,000. With land costs taken out of the development costs homes can be deployed at social rent values far more easily than any other form of development.

5.3 Geaneasain: Off site Construction - Natural & Healthy

MAKAR (2019)

MAKAR in inverness have been developing and refining a prefabricated panel housing system for many years. It utilises healthy, natural materials to include considerations to passively regulate the indoor environment. In 2013 they produced the Larch House and have refined design to develop the Geanaisean **in** 2019.

The Geanaisean is a three-bedroom certified PassivHaus in a garden site on the outskirts of Strathpeffer, Ross-shire. The house was manufactured off-site, using a timber-based ecological construction system. The design responds to solar access to the south and woodland views to the east. The form factor ensures minimal heat-loss, with generous overhangs to avoid overheating. Internally a variation of ceiling heights provides a mix of cosy and airy spaces.

The primary aim was to achieve a super-low energy home, whilst maintaining the use of ecologically-sound materials, constructed in a progressive manner. Both the client and the designer / builder MAKAR felt that the PassivHaus standard is often achieved without consideration of the environmental impact of materials or the manner of delivery, and were keen to challenge this.

The standard MAKAR system - off-site, timber-based panels - required minor amendments in order to fully comply with the PassivHaus criteria. The main challenges were eliminating thermal bridging, and ensuring sufficient insulation depth in the available standard dimensions of Scottish-grown timber. The solution was the MAKAR standard Warmcel-insulated timber frame, with an outer layer of tongue and groove wood fibre insulation board. Careful detailing at junctions ensured a continuous insulation jacket. The construction is a 'breathing' wall construction, which allows moisture vapour to dissipate naturally through the wall. All timber is untreated, thereby providing a stable and comfortable healthy indoor environment.

OSB board was used as an internal air-tight layer, and taped at junctions. This removed the requirement for membranes that are prone to damage during construction. Careful detailing, precision and cleanliness on site were key to success, with the house achieving 0.34 air changes/hour @50Pa. The kit was manufactured off-site at the MAKAR facility. This allowed for a high degree of quality control, which is key to achieving the rigorous PassivHaus standards. Operatives work in a heated and well-lit workshop, with panels laid horizontal for easy access. Details could be checked in person with the PassivHaus Designer prior to site assembly, with cladding, doors, windows and roof lights all installed in the factory.

With the standard MAKAR system already meeting the majority of PassivHaus criteria, the jump to certifying was not onerous. However, it has been recognised that the most important achievement was in developing a Passive-compliant system that can be replicated time and time again. It is hoped that continued demonstration of healthy insulation materials will actively encourage the UK manufacture of similar products, rather than relying on imports from continental Europe.

Although the house requires very little by way of space heating, the client chose to install a wood burner boiler stove, which supplies hot water to two radiators and all domestic hot water. The hot water is supplemented by solar thermal and PV panels (linking to an immersion heater, mostly used in the summer months). A rainwater harvesting system supplies water to the WCs, washing machine and garden. A car charging point is located by the main door. This model allows the client extremely low running costs. It is worth noting that the super-low heating demand of the PassivHaus means that a much of the equipment is not essential, and a far simpler, lower cost heating system could be used, whilst still providing low running costs.

Image 11: Geaneasain provided by MAKAR

Passive House Certified

Windows average 0.81 W/m2K

Floor 0.07 W/m2K

Walls 0.10 W/m2K

Roof 0.10 W/m2K

5.4 Material Passports –Triodos Office, Netherlands (2019)

Architects – RAU Architects

Completed in 2019 the new Triodos Bank HQ in the Netherlands is a 13,000m^2 office, which claims to be energy-neutral. It is constructed from a modular demountable, wood-hybrid construction so that the entire office can potentially be rebuilt in a different location without generating any waste flows - a 100% ‘reconstructable’ office building.

Image 12: Triodos Bank – Rau Architects

The CO_2 footprint of the building is reduced by using primarily timber construction with a glu-laminated timber frame and cross laminated floors and cores (1600m^3 of laminated timber and 1000m^3 of CLT). The basement is concrete due to water management issues.

The building utilises a green roof and water re-use of different types. Over 3000m^2 of solar panels and heat and cold storage contribute to the energy neutrality of the building. PV’s are mounted over the car park and supply the building and electric cars.

The Architect, Thomas Rau, is working in the Netherlands to develop a public database of materials in existing buildings and their potential for reuse. The aim is to track the provenance and performance of every element of a building, giving it an identity that can support reduction of waste in building construction. This concept has developed more specifically into ‘material passports’ that are a digital record of the specific characteristics and value of every material in a construction project, thereby enabling the different parts to be recovered, recycled and reused.

Rau Architects have put the principle into practice at Triodos Bank. With developments in BIM (Building Information Modelling) the material passport can be another layer of data that can be incorporated and tracked throughout a building’s life. This promotes the re-use of a material at the end the end of its useful life supporting the circular economy concept. The Dutch government has introduced tax incentives for developers who register material passports for their buildings, and it is considering making it a mandatory requirement for all new projects, in line with its ambition to achieve a circular economy by 2050.

The concept is also based around the importance of anticipating possible changes as far as possible when designing buildings - changes in user requirements, differences in the useful life of building components or external influences such as changing regulations or climate change. In that respect the concept links to the notion of future proofing for climate change and design flexibility and adaptability.

5.4.1 References

i. Triodos Bank / RAU Architects 13 Oct 2019. ArchDaily. Accessed 28 Feb 2020

ii. The case for…never demolishing another building 13 Jan 2020. The Guardian

iii. Cheshire, D. (2016) Building Revolutions – Applying the Circular Economy to the Built Environment, RIBA Publishing

5.5 One Planet Living: More than Housing: Hunziker Ariel (2007–15)

Architects – Various

Completed in 2015, More than Housing is a co-operatively organised quarter built in the Hunziker Areal in Zurich. It comprises 13 residential buildings for around 1400 inhabitants and 150 workspaces. The project was conceived as a test for a broad range of housing innovations based around questioning the autonomous individual and family in favour of a more societal approach to sustainability.

Image 13: Hunziker Real

The project is based on the 2000 Watt society model (a tool for sustainable city planning) developed by Swiss Federal Institute of Technology and adopted by the City of Zurich. The model seeks a reduction of individual energy use to a level that would be supported by a continuous 2,000 watt generator. The average at present in Switzerland is approx. 5,000 watts / person. The requirement is the equivalent of 17,520 kWh/year. The energy performance of a house in intended to be low enough so that people can live in it and achieve the 2000-Watt target with realistic changes to their lifestyles. The promotion of sustainable lifestyles outside that of the energy used for heating and hot water energy usage is a key part of the project. The target includes aspects such as travel, food and consumer items – far beyond that considered by building regulations/ ‘regulated’ emissions or PassivHaus standards. The approach therefore extends into to the remit of urban planning and the requirement for individual and collective lifestyle changes.

So far, the living habits of the residents have not yet reduced to keep energy consumption within the 2000 Watt target but the design and lifestyle initiatives promoted in ‘More than Housing’ have helped to work towards this objective.

The development is based around the principle of ‘helping people to help themselves’ and includes various forms of co-operative ownership and affordable rents. Participation in the design development was encouraged from the outset. Residents are also supported to participate in ongoing community life - develop farming, communal gardens, establishing a grocery shop, café, swap shops, dancing and yoga classes. On site there is childcare, a bakery, shops, restaurants, a bed and breakfast and working studios/workplaces. Housing units are mixed size units with allowance, for example, for the requirements of an ageing society designed in and various forms of space sharing available. Common spaces, shared community spaces are also included.

Other key notable features of the scheme include:

- Environmentally friendly homes for people from a wide range of backgrounds and income levels;

- An attempt to anticipate future needs of the community and design buildings and ways of living that meet them;
- Provision of homes with shared spaces and allowing for different people - nuclear families, single people, couples, extended family etc.;
- User participation including focus groups for design with residents, neighbours, founding coops and authority representatives;
- Certain areas left unfinished so residents could decide how the spaces would be best used;
- An annual budget is available for community initiatives from contributions from residents;
- Low energy design to levels to reasonably allow people to achieve the 2000-watt target;
- No individual washing machines but communal shared free laundrettes (energy efficient machines);
- Centrally located freezer lockers for rent;
- Approx. 45% electricity through photovoltaic cells on the roofs;
- A District heating system;
- Consideration of Low embodied energy materials – solid timber construction techniques;
- Almost car free design with good public transport links and bike parking established and parking provided for retail units and for those with access requirements – encouragement of utilisation of the national car-sharing scheme - two electric cars and bike sharing pool;
- Buildings designed so neighbours meet and interact in everyday life to foster communal living;
- Cluster apartments - small units with bed, bathroom and kitchenette around large common spaces;
- Large community facilities like sauna, restaurant, laundry repair / swap shops, meditation room;

The house space standards in the scheme are generally limited to an individual footprint per person of 34m^2. The principle of limiting space standards addresses a reduction in energy use (normally measured per m^2), a general reduction in resources in the building fabric and a reduction in land take (Thomas 2019). This concept of 'Energy Sufficiency' is also noted at Vauban in terms of medium density urban development compared to detached dwellings.

5.5.1 References

i. Hugentobler, M., Hofer, A. (2015) More Than Housing – Cooperative planning – A Case Study in Zurich, Birkhauser;

ii. Thomas, S. and Bierwirth, A. (2019) Energy Sufficiency in Buildings: Concept Paper, ECEEE

5.6 Use Recycled Materials - Brighton Waste House (2014)

Architects - BBM Sustainable Design

The Demonstration Waste House was commissioned by the University of Brighton. The project was led by Duncan Baker Brown and designed and constructed in collaboration with students at the University. Its aim was to demonstrate that many under-valued materials that are commonly referred to as waste (construction and domestic) have the potential to become valuable resources. It also demonstrates that these materials and technologies can be used in a self-build context using a professional approach.

Image 14: The Recycled House – Photo: Halliday 2017

Partly fabricated offsite the $85m^2$ house was completed on site between May 2013 and April 2014. It was designed to meet normal planning and building regulations but using approx. 85% of material from waste. The house has an EPC Rating of A and is defined as 'carbon negative' as it creates 25% more energy than it consumes.

The construction is based on a salvaged timber and plywood primary frame with plywood 'wall panels' or 'cassettes' between the frame. The required insulation values are based on an IES (Integrated Environmental Solutions) model and were achieved by securing returned or damaged polyurethane insulation (for use in the construction of buildings) to the outside of the frame and cassettes. Foundations are concrete but it is based on a 40% reduced cement content and incorporates ground-granulated blast furnace slag plus aggregates from demolition sites. Poor ground conditions meant it was not possible to avoid cement specification.

Other notable salvaged materials used in the project included timber joist floor and roof elements and drywall offcuts from other sites used as interior linings with the required joints expressed. An internal rammed earth wall from chalk spoil added thermal mass while discarded vinyl exhibition banners with taped joints were used for vapour control. Other approaches included – internal paints from New Life – reprocessed waste water-based paint as premium grade emulsion and a roof rubber membrane made form Pirelli car tyres.

Sourcing of material mainly involved pooling of local networks and therefore often involved material obtained from other sites known to the design team. This was combined with using 'Freegle' (a free Internet-based service where people can give away and request things that would otherwise be thrown away) to source materials UK wide. New materials used on the site included high performance windows and doors as second hand products were difficult to source and their performance considered unreliable. Other notable new materials include first fix services due to reasons of health and safety and reliability.

Early involvement of building control was important in the project in ensuring the suitability of material choices and the local authority building control team were therefore an integral part of the design team. Fire treatment of the reclaimed carpet tiles used for the external cladding and some internal plywood lined walls were the main challenges in terms of building regulation compliance.

Baker Brown (2017) notes some key lessons from the project. The first was the engineering requirement of using reclaimed timber and clearly defining its structural properties. The worst-case structural property had to be assumed in many cases. This point relates more generally to the use of innovative materials in terms of design liabilities and skills available in the design team and building control. Another key lesson was the component of time and having materials available when needed. Critical here are the development of local information systems, appropriate storage and procurement processes. This links to concept of material passports discussed elsewhere in this report.

The zero waste house is one of a growing number of projects dealing with the circular economy, cradle to grave, cradle to cradle, close loop supply chains, often but not always involving the integration of less conventional bio-based building materials (see Triodos Bank Case Study and TAM above). Specifically however it deals with the use of waste materials rather than the 'passporting' of new materials.

Other notable examples include the Upcycle Studios,[79] a terrace of live-work units that uses recycled concrete, reclaimed oak floors, aluminium from recycled cans, and new thermal windows made by combining two reclaimed double glazed panels. Concrete usually either ends up in landfill, or is crushed for use in roads, but this project shows that waste aggregate (1,700 tonnes) can make high quality new concrete, reducing the consumption of virgin materials by almost half.

5.6.1 References

i. Baker Brown, D. (2017) *The Re-use Atlas*, RIBA Publishing, London

ii. Mark Gorgolewski (2017), *Resource Salvation*, Wiley-Blackwell

iii. Rau, T. from Leising, E. (2016) *Circular supply chain collaboration in the built environment*. MEI Thesis, Leiden University and Delft University of Technology with KPMG Sustainability

[79] https://urbannext.net/upcycled-studios/

5.7 Car Parking - The Hidden Cost[80]

Gaia Architects

A study undertaken by Gaia Architects into the impact of car parking revealed some interesting outcomes.

The study compared the footprint assigned to the car compared to the footprint assigned to people for a number of different building arrangements – a detached house, and terraced housing with a range of alternative parking arrangements.

The resulting ratios indicate that detached housing dedicates 32 x as much footprint to the car per occupant per house of use as it does to the house.

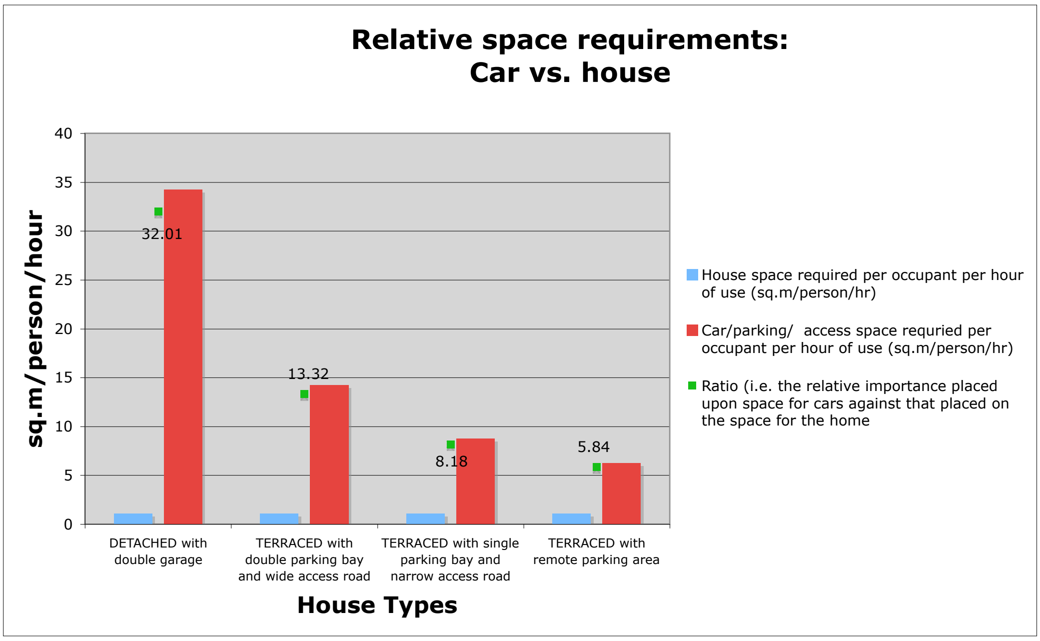

Image 15: Relative space requirements of cars and houses for differing build types.

[80] See Case Study 3.7 Halliday S.P 2018 Sustainable Construction Routledge

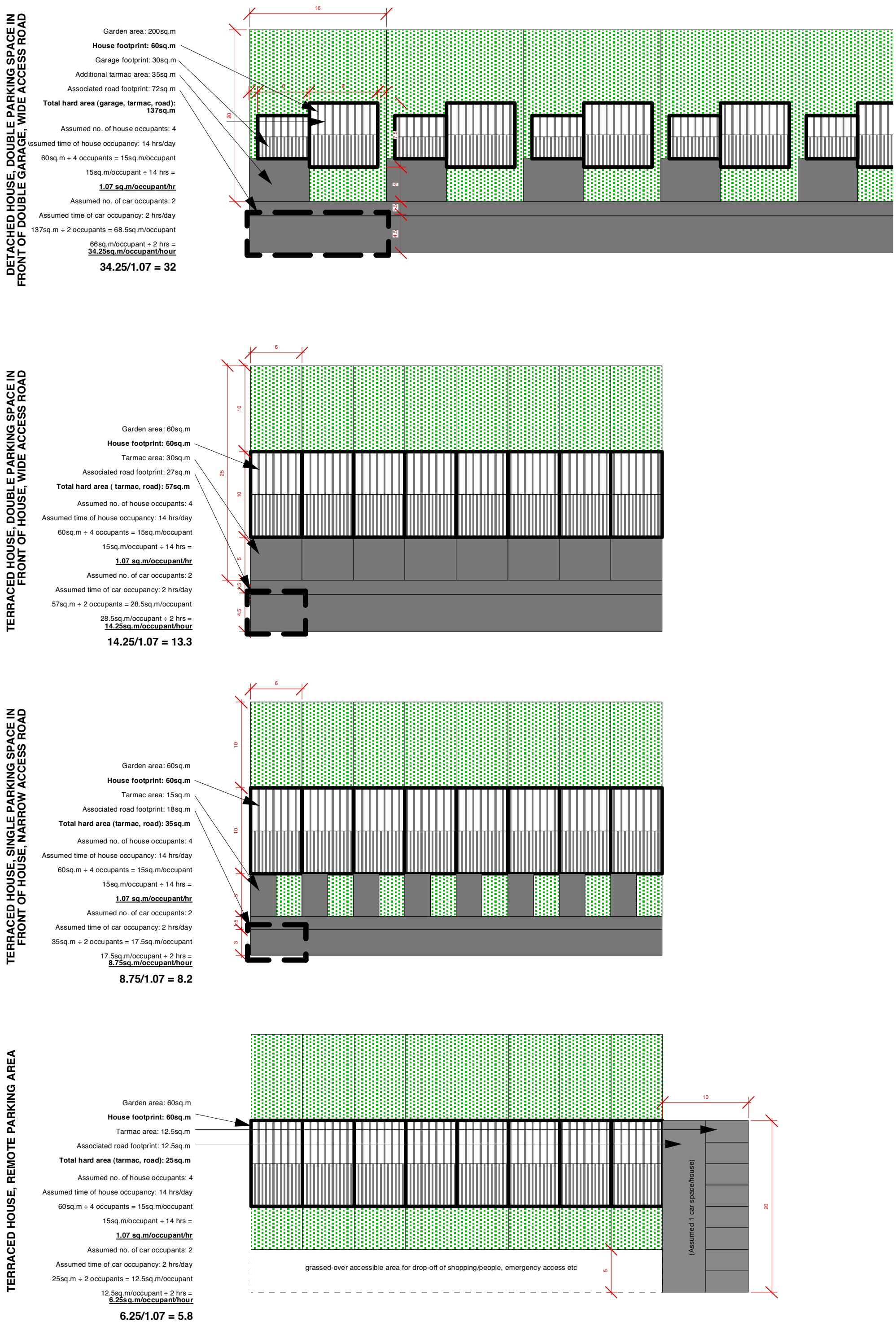

Image 16: Assumptions regarding space requirements of cars and houses for differing build types.

5.8 The Biotope Factor - Spreefeld - Urban Green, Berlin (2017)

CarpanetoArchitekten + FatkoehlArchitekten + BARarchitekten

A city's ecological footprint can be reduced through protecting biodiversity and green spaces, limiting the expansion of road networks, reducing sprawl and promoting higher densities.

An estimated 20% of Berlin is protected woodland and 46% is green or blue space. The explanations for this extraordinary green space conservation vary from a background of Soviet-style planning, to the concept of "people parks" dating to the 1870s, and the restriction on travel imposed by the Cold War required area for recreation locally.

Image 17: Spreefeld Coop Housing – Photo: Halliday

Berlins' urban planning has prioritised open green areas since the early 1900's. In a large part of the city there are binding Landscape Plans in which any new development must have a proportion of green space determined by the ratio of green space to total space - the Biotope Area Factor (BAF/BiotopFlächenfaktor BFF).[81] This can be up to 30%. Spreefeld Coop Housing has been developed to meet the requirements of the Biotope factor.

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[81] https://www.berlin.de/senuvk/umwelt/landschaftsplanung/bff/index_en.shtml

As there is huge support for the policy it is used widely on a voluntary basis. It is flexible. A developer can choose green space measures freely, so long as the overall requirement is met. Different types of green space have a weighting based on: evapotranspiration quality, permeability, rainwater storage capacity, connection to soil functioning, and provision of habitat. For example, a surface is counted 100% if it has vegetation connected to the soil below and supports flora and fauna. But vertical greenery (e.g. on walls) up to 10m in height is counted at 50%.

The legally binding Ausgleichmassnahmen (Compensation Measure) is also built into nature conservation legislation and building permits to compensate for green areas lost in urban development. Developers are required to offset land development by investing in an equivalent amount of green space. In each case, the most appropriate compensation is found from the existing inventory of all areas in Berlin, prioritising where there is a lack of greenspace. The developers of PotsdamerPlatz spent €22 million on Gleisedreiek Park. There is also a legal obligation to check the effectiveness of the compensation works.

Other examples include the FalkenbergerKrugwiesen extension of semi-natural grasslands around a lake in compensation for a highway, and the Mauerpark, in compensation for the high-speed Berlin-Hanover rail link.

There are also a range of practices that boost biodiversity, such as varied habitats, human introduction of species, and dispersion of species from large-scale protected areas.

5.9 Collective Resource Efficiency - LILAC (2013)

Architects – White Design

LILAC (Low Impact Living Affordable Community) was developed for the Mutual Home Ownership Society Ltd. (MHOS) a registered Co-operative Society formed in 2009. The project started on site in 2012 and was completed in 2013. LILAC's primary aim is to reduce the overall ecological footprint of the neighbourhood through positively changing the way the residents live, use energy, and interact in the community.

The development consists of 20 houses and flats arranged around a car free communal garden with play area and central pond used as part of the site wide sustainable urban drainage scheme. The houses and ground floor flats also have small private gardens and the upper flats balconies. A shared central 'common house' accommodates a post room, communal cooking and dining facilities, a kitchen and pantry, office, workshop, guest room and laundry facilities. The 'common house' opens onto a communal court and provides a focus for the main site access. Some of the site is given over to allotments for use by the MHOS and other local residents. Bike sheds and small communal parking areas (10 cars for 20 units) developed from a detailed travel plan as part of the planning process.

Image 18: Low Impact Living at LILAC – Photo: Halliday

The houses and flats at LILAC are built using Modcell, a mixture of cross-laminated timber framing with straw infill external structural wall panels. The panels are finished with lime render and untreated timber cladding between panels. The panels are combined with timber floor systems. The low U-values of the straw insulation and glazing systems combine with the MVHR system to develop a low energy solution supported by PV's. The insulation levels are less than PassivHaus standards with the scheme developed around a more broadly based approach to the sustainability of the whole community and carbon sequestration in the building fabric.

The project reflects and develops on earlier Danish and Dutch Co-housing models e.g. Woon Kollektief (1985) and Buziaustraat (1992) both in its organisation around communal gardens and the central provision of shared facilities. Often such schemes part funded communal provision by reduced individual provision e.g. kitchens. At LILAC shared facilities, car sharing, meal sharing in the communal kitchen, pooling of equipment and tools (lawnmowers, drills and washing machines) support social interaction while potentially reducing carbon footprints. LILAC has also consciously become a resource for the wider local community both in terms of the co-house and its terrace and use of allotments. It provides a clear example of a sharing economy. This approach can also lead to a reduction in space requirements through the efficiency of shared provision and relates to the discussion on Hunziker Ariel and Vauban above.

The site concept, unit types and detailed landscape approach were developed through a series of intensive workshops with the current housing group along with occasional wider consultation events held during the design development stages. The Modcell system was requested by the client and was a fixed element during these workshops. Initially the project was to include an element of 'self-finishing' later discounted by the group due to the realities of fitting this in to their working days.

The co-housing group recognised the importance of not being or being perceived as a gated community while also recognising the importance of the natural surveillance of the communal areas and the need to support wider community interaction formed during these participatory sessions.

MHOS is a new way of owning a stake in the housing market. It is designed to bring the bottom rung of the property ladder back within reach of households on modest incomes in areas where they are priced out of the housing market. The ownership model supports affordable housing provision but also allows release of some capital on leaving the MHOS.

LILAC is responding to housing affordability issues, low carbon footprint buildings (in use and in their fabric) and community issues around sustainable interaction, positive contribution to the surrounding and the efficiency benefits of shared living. Paul Chatterton one of the original MHOS and driver of the LILAC vision describes LILAC as "a prototype of low impact living drawing on a co-operative and co-housing model that reduces a community's ecological footprint through the use of highly insulating and carbon sequestrating natural build materials such as lime, timber and straw, as well as developing a sharing economy between neighbours." (Chatterton 2019)[82] He notes the term LILAC was used deliberately to focus on the need to build places based on economic equality, social justice and ecological sustainability.

5.9.1 References

i. Chatterton, P. (2019) Unlocking Sustainable Cities

ii. Halliday, S. (2019) *Sustainable Construction*, Routledge

iii. Nash, C. (2016) Contemporary Vernacular Design, RIBA Publishing

iv. Hutchison, K. (1995) Toward Architecture of Social Ecology, PhD Thesis Liverpool University

[82] Film. Scotland's Housing – More than Just Numbers (7 mins) https://youtu.be/6Z6Rc7WSyzQ

5.10 Responsible Landlord – Dormont Park Passivhaus (2011)

White Hill Design Studio with Scottish PassivHaus Centre

Dormont Park comprises 8 no. new build 2 and 3 bed semi-detached homes on a rural site near Lockerbie, Dumfriesshire. The scheme is private rented housing but intended to provide long term affordable rent to local households in priority need. The estate is an accredited landlord under the Landlord Accreditation Scotland Scheme – a voluntary scheme that demonstrates that landlords operate to a high accredited management standard. The scheme also aimed to reduce fuel poverty through its low energy design.

The scheme was provided partial grant funding through the Scottish Government's Rural Homes for Rent pilot programme. This however made no provision for the costs of the targeted Passivhaus standards and to deliver the houses within normal commercial budgets was a key target. The Building Performance Evaluation Report commissioned for the project notes the project was delivered without excessive on-costs (MEARU 2015). A reduction in house size at design stage helped achieve this aim.

The homes are to Passivhaus standards with a primary energy demand target of 120 kWh/m^2/annum. They are designed on an east-west axis with large south facing windows to make use of passive gain. Each house is orientated and constructed identically. The MVHR is fitted with a heater fed from the hot water tank to provide heat boost as required. Hot water is entirely from renewable energy – either solar thermal panels - or back boilers to small log burning stoves that provide minimal heat to the rooms. Initial assessment by MEARU show that a 'zero carbon' balance was unlikely due to the lack of onsite electrical energy generation. The use of locally produced timber from the estate was however noted.

Image 19: Dormont park case study– Photo: Halliday

U values:

- External Wall – 0.1 W/m^2K – mineral wool between 260mm I studs, 70mm PUR boards internally – larch or render on render board cladding
- Roof – 0.1 W/m^2K – pitched mineral wool between 300mm engineered rafters, 55mm PUR boards beneath
- Ground Floor - 0.1 W/m^2K – 200mm rigid XPS over RC Slab
- Windows and Doors - 0.8 W/m^2K

Air Tightness – 0.6ac/h@50pa

ProClima Intello airtight layer to internal face of rigid insulation

A two-year study in 2012 to 2014 showed that the heating, lighting and hot water of a 3 bedroom (6 person unit) cost - as little as £100 a year- had a significant impact on tenants as regards fuel poverty. According to the Architects website it is estimated that under the building regulations in force in 2011 each house would have emitted 63 tonnes of CO_2 /yr but that by building to certified PassivHaus standards and utilising solar and biomass energy this is reduced to 3 tonnes of CO_2 /yr.

The BPE report findings note that:

- Energy efficiency was excellent in comparison with most other Passivhaus and Low Energy buildings monitored by MEARU;
- The Passivhaus approach has been shown to be an effective way to ensure energy efficiency;
- Occupants have significantly affected the overall energy consumption and performance of the buildings;
- The off-site construction process was a success generally although possible improvements to thermal bridging were noted as a priority and the air-tightness, while low, did not quite achieve the Passivhaus requirements;
- In general the environmental conditions have been shown to be very good with the main concern being the prevalence of overheating in warmer weather - the landlord has worked with the tenants to reduce the occurrence of this;
- A role of the landlord was important in maintaining relations with tenants through the process.

The homes were built using closed panel timber frames manufactured off-site enabling waste minimisation in fabrication otherwise fabric/embodied carbon and waste reduction/closed loop systems were not part of the brief. Timber was not locally sourced and insulations were chosen for performance not embodied energy. Neither were wider lifestyle issues outside that of individual house energy performance part of the brief. The development is rural and transport generation is not factored into energy savings.

5.10.1 References

i. Glasgow School of Art, Mackintosh Environmental Architecture Research Unit (MEARU), (2015), *Innovate UK Building Performance Evaluation, Dormont Park Passivhaus Project*

5.11 Plummerswood Active House (2011)

Gaia Architects

Image 20: Photo, Halliday

Plummerswood was designed to a certified passive standard specification with a designed natural ventilation strategy to make it capable of operating in natural ventilation mode.

5.11.1.1 **Design approach**: a contemporary 3-bed timber house on an east-facing wooded slope, designed to reflect the scale and grandeur of the clients previous mid-18thC house and to capture the incredible views southwards down the Tweed Valley.

5.11.1.2 **Off site construction -** Built from Brettstapel[83] to achieve Passivhaus;

5.11.1.3 **Layering and design for disassembly:** The superstructure was manufactured and built by the same Austrian company as Acharacle. All layers are sequential, i.e. assembled in a way that allows it to be taken apart again, either for maintenance or at the end of its life.

5.11.1.4 **Massing:** The house has a form factor of approx. 2.3 (~805sq.m exposed surface area/~350sq.m treated floor area), which is below PH threshold of 3.

5.11.1.5 **Landscape strategy**: use of an existing level area on the sloped site to minimise excavation. Predominantly natural regeneration of birch and scrub woodland following felling of the original commercial Sitka spruce plantation.

5.11.1.6 **Supply chain:** Borders-based principal contractor responsible for services, foundations, substructure and internal fit-out; Austrian-based subcontractor responsible for manufacture, supply and erection of pre-insulated Brettstapel superstructure of external walls and roof panels;

5.11.1.7 **Construction strategy and detailing:**

- Floors: Reinforced concrete slab under whole building except sitting room, which is supported on a steel superstructure due to ground levels. Woodfibre insulation fitted over concrete slab, with floor finish over. Sitting room floor constructed from pre-insulated timber cassettes;

[83] http://www.brettstapel.org/Brettstapel/What_is_it.html

- External walls: cladding (local stone/local larch/fibre cement) on battens forming ventilated void; 340mm rigid woodfibre;
- Insulation; 16mm wood-based airtightness board; 80mm thick Brettstapel with exposed internal surfaces;
- Roof: single ply TPE membrane (least polluting on offer at the time); 360mm rigid woodfibre

5.11.1.8 **Air-tightness, it achieved (0.6 $m^3/hr/m^2$ @ 50Pa (0.46 ac/h^{-1}).**

- Insulation: 16mm wood-based airtightness board laid to falls with flexible insulation between; 140-18

6 Overarching Principles For Resource Efficient Housing 2020

Resource efficiency is essential because we live on a finite planet. It is impossible to continue to infinitely consume finite resources, meaning that careful use and re-use are fundamentally important. The upfront resources and toxicity in re-use is equally important as responsible manufacturing of cradle to cradle ready products

As noted in Section 2 there are many types of resources, all of which can be turned into waste through careless use. Distilling 'resource efficiency' for housing into a set of principles inevitably relies on some over-simplification of precisely *which* resources we must aim to use and the level of *efficient* use that will ensure their sustainability. With this in mind we consider efficient use of the following finite resources: **land**, **materials, health, energy, carbon** and **water**.

6.1 Land

Humankind occupies a small proportion of the earth's surface, usually being located where climate, topography and resources are most favourable for agriculture and settlement. Urban and built up areas, which house around 55%, or 4.2 billion, of global population,[84] account for 0.007% of the earth's land surface,[85] around 1.5m km^2. The remaining 45% of global population is spread across six continents, with less-industrialised countries tending to have higher proportions of rural population.[86]

The United Nations predicts that the global population will increase from 7.63bn to 9.85bn between 2018 and 2050.[87] Based on the continuing trend of rural populations migrating to urban areas, driven largely by industrialisation and economic development. They anticipate the proportion of people living in urban and built up areas will increase to 68% by 2050. The logical end-point for this flow is an entirely urban population at some point in the near future.[88]

6.1.1 Land Availability

Within the scope of this report, fair and equal access to land is an issue of fundamental importance to achieving efficiency of land resource. In Scotland around one-fifth, 17,000km^2, of land is privately owned by fewer than 100 families[89], restricting its fair and sustainable use. Land banking by private developers who retain land and build on it at a rate that maintains housing as a scarce, and therefore expensive commodity, exacerbates the problem.

One potential solution, suggested by Kennedy,[90] is to apply a fixed annual 'use charge', for example 3% of land value, on all land *irrespective of ownership*. The charge to private landowners would be paid to local government for use within local communities. Landowners would have the option to transfer ownership of the same value of land, rather then a cash sum, eventually resulting in community ownership of that land. This would have the likely effect of major transferral of land

84 https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html
85 https://ourworldindata.org/land-use
86 https://www.worldatlas.com/articles/working-on-the-land-the-world-s-major-rural-populations.html
87 https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html
88 https://www.nationalgeographic.com/environment/habitats/urban-threats/
89 https://landcommission.gov.scot/our-work/ownership/scale-and-concentration-of-land-ownership

90 https://userpage.fu-berlin.de/~roehrigw/kennedy/english/Interest-and-inflation-free-money.pdf

ownership and annual income for community development. It would be particularly effective in rural areas, which have greater areas of land.[91]

Debate about whether continued rural-urban migration is desirable is intense. Urbanisation offers benefits in terms of access to social infrastructure. Although its proponents largely see it as a positive influence on economic development and as an indicator of 'progress', i.e., the business as usual scenario that drives the current economic migration for urban employment. However, to paraphrase E.F. Schumacher, what is 'progress'?[92]

People drive flows of materials, energy and waste. Increasing population density and demands of urban environments naturally result in high flows of these resources such that cities occupy 2% of land but are responsible for **67-76**% of energy use, about 75% of global CO_2 emissions and generate 85% of global waste.[93] This results in poor air and water quality, water shortage, waste-disposal problems, and high energy consumption, without necessarily relieving the poverty gap that drives it. Cities have huge levels of social and economic inequality. Excessive urban land use, pollution and inequality are compounded by almost unrestricted construction of low-density suburban housing.[94]

To deliver genuine improved life quality in cities within a 1-planet living context will require strong city planning and attention to waste and pollution in all its forms. An approach defined by Urban Ecology.[95] The alternative to support communities and economic development in smaller settlements and rural environments has been, to date, an unfulfilled aspiration. It retains a strong presence in the UN sustainable development goals.[96]

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91 If land was to distributed equitably then Scotland has a land mass of 78,352km2 91 and population of 5.47m (201991), equating to around 14,300m2 (1.43Ha/3 acres) per person

92 https://www.schumacherinstitute.org.uk/about-us/e-f-schumacher/

93 IPCC 2018

94 Average global population density in urban areas is 2,800 people/km2 or 357m2/person94. For comparison, Glasgow94 has a population density of 3,400 people/km2; Edinburgh 1,83094 and Inverness 2,95894. Average population density across the world is around 60 people/km2 or 16,000m2/person 94.

95 Urban Ecology in Halliday S.P 2018 Sustainable Construction Routledge

96 https://sustainabledevelopment.un.org/topics/ruraldevelopment/decisions

Image 21: UN Sustainable Development Goals

While the prevailing UK volume house-building model of detached dwellings arranged around a road layout clearly demonstrates high levels of energy and material waste it is, also fundamentally, a waste of land that could have a variety of other uses. There are implications for housing size. Adequate physical internal space in the home is essential for health, wellbeing and the ability to undertake a range of normal activities in comfort. However, the provision of too much space per person can result in higher energy demands for heating, lighting and ventilation.

For housing to achieve **land efficiency** the following principles must be established:

1. National socio-economic centres, and the industrialisation and economic development that create them, must become more evenly distributed;
2. Small settlements and rural areas must receive the same support as medium and large socio-economic centres to encourage distribution of wealth and reduction in the need to travel;
3. Housing must be integrated into socio-economic centres – not relegated to peripheral zones – to reduce travel distances to work, education and recreation;[97]
4. Land ownership must be reformed to enable groups of people to build together;
5. Housing density must be increased in all areas to help improve energy and material efficiency.
6. All new housing will provide 30sq.m internal floor area per occupant. Occupant density of existing housing will be determined using 30sq.m per occupant;[98]

[97] Cities of small distances - Hamiduddin I., (2018) Journey to Work Travel Outcomes from ‘City of Short Distances’ Compact City Planning in Tübingen, Germany, Planning Practice & Research, 33:4, 372-391, DOI: 10.1080/02697459.2017.1378980

7. Sharing of spaces and common facilities must become normal practice. This includes vehicles, clothes washing equipment, kitchens and dining areas, tools and equipment.
8. Biotope concept – the dedication of an agreed percentage of land to leisure and biodiversity [99]

6.2 Materials

In 2017 more than 100,000,000,000 –100 billion – tonnes of materials were extracted from the earth. This is nearly four times more than the 26.7 billion tonnes extracted in 1970, but only around half of the extraction predicted by 2050[100]. Around half of all extracted materials are consumed by construction and infrastructure projects around the world.

The latest figures for material consumption by the construction industry are for 2015 and suggest that around 300 million tonnes were used across the UK. (No independent Scottish data have been identified.) Of this it is understood that more than one-third ended up as waste[101]. Extraction, processing and transport of these materials results in major pollution of land, air and water.

Construction materials can be split into those made from minerals (e.g. stone and earth products for concrete, bricks and tarmac), metals (e.g. bauxite, iron and copper ore), fossil fuels (e.g. oil and gas for petrochemical and plastic products) and biomass (e.g. timber and other plant-based crops used in construction). To reduce material waste it is essential to limit the use of virgin, non-renewable materials, to move to plant-based and renewable construction materials that can eventually return to earth, and to re-use existing non-toxic materials in their original state as often as possible.

Material waste is often created through the complexity of building assemblies: timber framed walls, for example, can have as many as *eleven* separate layers of components. This is significantly more than, for example, strawbale walls, which have *four* layers of components and are equally insulating and draughtproof. Components that penetrate assemblies, for example structural steelwork passing through insulation layers to form a balcony, add complexity (and reduce thermal performance). Each layer presents an opportunity for waste to be created. Reducing construction complexity is essential in reducing waste.

Recording the location and nature of materials and components within the construction cycle is essential if we are to be able to re-use them in the future. Many examples exist of digital 'materials passports' that do exactly this. When integrated with building information modelling (BIM), blockchain and digital twinning it is possible to create a complete digital record of a building. The value of this is greatest at maintenance and disassembly points, when information on materials and components can be easily accessed and used to guide decisions. This approach also records the inherent value of materials and components. As the construction industry moves towards circularity the financial and carbon value is likely to increase.

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[98] Energy Sufficiency:- https://www.energysufficiency.org/libraryresources/library/items/energy-sufficiency-in-buildings-concept-paper/
[99] Biotope Concept https://www.berlin.de/senuvk/umwelt/landschaftsplanung/bff/index_en.shtml
[100] https://www.businessgreen.com/news/3085100/business-as-usual-is-dead-global-resource-use-smashes-past-100-billion-tonnes
[101] https://www.ukgbc.org/resource-use/

Maximising re-use of materials and components relies on careful design and installation to allow for simple disassembly and re-use. It also relies on the complete elimination of toxins from the material and component chain. Despite guidance on 'Design for Deconstruction'[102], Design for Disassembly'[103] and 'Design for Reuse'[104] being widely available, little legal or fiscal incentive exists to encourage its adoption.

For housing to achieve **material efficiency** the following objectives must be achieved:

- Existing housing must be retained and refurbished to prevent waste from demolition and in future use;
- Design lifespan for all new buildings must be at least 200 years to reduce the need for, and frequency of, disassembly and the associated energy required and potential waste generated;
- The need for short-life buildings must be eradicated as far as possible through good planning;
- All materials and components – including internal furniture, fittings and equipment – must receive a 'passport' with details of essential characteristics including toxicity, embodied energy, carbon and how they are re-useable;
- Re-used materials and components are permitted as long as they do not contain chemicals on the Living Building Challenge Red List[105]
- Recycled materials and components are permitted as long as they do not contain chemicals on the Red List and do not compromise the achievement of zero upfront/embodied CO_2.
- BIM and digital twins must be adopted as integral parts of the design, construction and disassembly process;
- Construction complexity must be reduced, so that the number of construction layers is minimised and penetration of layers is avoided;
- All materials and components must be assembled in a way that allows them to be easily disassembled in the future.

6.3 Health

The health and wellbeing of human populations is an essential resource. Its importance is often overlooked as it does not contribute to conventional measures of national prosperity. In the absence of human health, however, society quickly suffers due to impacts on essential services and infrastructure, and economic productivity.

The location, layout, design, materials, construction and maintenance of homes has measurable impacts on human health and wellbeing. These extend from the houses themselves to the external space surrounding them. When these are properly considered and good decisions made, health and wellbeing is supported and enhanced.

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[102] https://www.seda.uk.net/design-guides
[103] https://www.ellenmacarthurfoundation.org/assets/downloads/news/EMF_Engineering-the-Circular-Economy_300913.pdf
[104] http://www.greenspec.co.uk/building-design/design-dismantling/
[105] http://www.greenspec.co.uk/building-design/red-list-of-banned-toxic-construction-materials/

For housing to achieve **health efficiency** the following objectives must be achieved:

- The principle of 'cities of small distances' should be adopted and applied to all settlements, whether new or existing. This must be based on the idea of '20-minute neighbourhoods'[106], where people live within a 20-minute walk of everyday services and needs;
- Housing must be arranged to prioritise solar orientation and greenspace over roads and parking;
- The design of the site will achieve Building with Nature certification.[107] All habitable rooms in homes will have a short-range view of greenspace;
- Soft landscaping must achieve a biodiversity index after 1 year of 0.25
- All soft landscaped areas must be capable of growing food, including fruit, vegetables and animals.
- Room arrangement in new houses will correspond to diurnal occupancy, e.g. east-facing bedrooms, south-facing sitting room, etc.
- Housing will be dual aspect to ensure good quality daylighting throughout the day and enable natural cross ventilation during periods of warm weather.
- Sitting rooms must receive daylight from more than one direction.
- Overheating will be limited to 10% of occupied hours over 25ºC
- All materials must be checked against toxicity criteria[108]. Materials must not be used if they contain any chemicals or compounds found on those lists:
    (1) Substitute it Now [109]
    (2) Living Building Challenge Red List [110]
- Predicted chemical loads must be calculated for homes using the IAQ Rating Index from Indoor Air Quality UK.[111]
- Occupants must be provided with guidance and support to make positive choices for furniture, furnishings and finishes that minimise chemical exposure in homes.
- All materials must be vapour permeable to enable moisture-transfusion at normal working vapour pressures.

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106 https://www.sustrans.org.uk/our-blog/policy-positions/all/all/our-position-on-how-walking-cycling-and-placemaking-could-help-tackle-the-housing-crisis/
107 Building With Nature https://www.buildingwithnature.org.uk/
108 http://www.greenspec.co.uk/building-design/toxic-chemistry-health-environment-pollution/
109 https://chemsec.org/business-tool/sin-list/
110 r https://living-future.org/declare/declare-about/red-list/
111 http://www.iaquk.org.uk/index.html

6.4 Energy

In 2015 Scotland consumed 142 Terawatt hours (TWh) of energy.[112] (One TWh = one billion kWh.) With a 2015 population of around 5.37m this equates to 26,443kWh of energy per person per year, or an average power demand of just over 3000 Watts – some 50% higher than the limit advocated by the 2000-Watt Society in order to meet planetary limits.[113]

In our homes we use **'operational' energy** for many tasks including heating, lighting, hot water, cooking, washing, ventilation, bathing and recreation. Of these only the *predicted* energy for heating, hot water and lighting in *new* homes – not existing homes – is regulated by Government. *Actual* energy use in homes is neither regulated nor assessed against predicted targets, resulting in a well documented 'performance gap'.[114] Our homes are significantly less energy efficient than they could be. Heating systems use more energy due to inadequate insulation and draught proofing, inappropriate orientation and inadequate solar gains; artificial lighting systems use more energy due to poorly placed and under-sized windows; hot water systems use more energy due to inadequately insulated storage tanks.

Creating and transporting building materials and components, and the process of constructing and refurbishing requires energy, referred to as **'embodied' or 'upfront' energy**. It is essentially a form of 'penalty' paid for construction and refurbishment. Despite being discussed in the construction industry for over a decade, it is not regulated by Government but, as buildings become more energy efficient to operate, it accounts for an increasing proportion of total energy use over a building's lifetime. Some materials and construction methods have significantly lower upfront energy than others[115] [116].

To reduce energy use to the limit advocated by the 2000-Watt Society we must cap both operational energy and upfront energy. Existing buildings have already paid the upfront energy 'penalty' for their construction. In most cases their refurbishment to achieve low *operational* energy use will result in lower *overall* energy use than the construction of a new building to the same level of operational energy efficiency. As such, refurbishment must, in most cases, take priority over the construction of new buildings.

For housing to achieve **energy efficiency** the following objectives must be achieved:

- Existing housing must be retained and refurbished – rather than demolished – to avoid upfront energy use required for new construction;
- Massing will be in the form of terraces and low-rise multi-storey. All new housing must have a form factor of ≤3. [117] Existing houses with a form factor greater than 3.5 must be optimised before considering increasing insulation thickness.

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[112] https://www2.gov.scot/Resource/0054/00541605.pdf
[113] https://www.2000watt.swiss/english.html
[114] https://www.designingbuildings.co.uk/wiki/Performance_gap_between_building_design_and_operation
[115] https://www.architectsjournal.co.uk/home/embodied-energy-traditional-masonry-vs-modular/8640369.article
[116] https://www.circularecology.com/embodied-energy-and-carbon-footprint-database.html#.XnvgLZP7TIE
[117] 'Form Factor' is calculated as total external surface area divided by 'treated' floor area.

- Where new housing is required it must be constructed from materials and methods with the lowest possible upfront energy requirement. This must not exceed the RIBA 2030 target of <300kgCO_2e/m^2.[118]
- All existing housing must be refurbished, and occupants provided with guidance, to reduce net operational energy consumption to achieve the RIBA 2030 target of 0 – 35 kWh/m^2/yr.[119] Overheating must be prevented in new and existing homes;
- All new housing must be designed and constructed so that net operational energy consumption achieves the RIBA 2030 target of 0 – 35 kWh/m^2/yr;
- All new and existing housing must be checked on completion, and annually, using Building Performance Evaluation and Post-Occupancy Evaluation, to ensure the operational energy and comfort targets continue to be met.

6.5 Carbon Dioxide Emissions

The earth has finite capacity to absorb and store carbon dioxide (CO_2) released through natural processes. This is termed the carbon cycle.[120] Atmospheric CO_2 is increasing due to anthropogenic activity, imbalancing the cycle and causing climate change and global warming. The Intergovernmental Panel on Climate Change has set limits on the amount of CO_2 humans should emit without causing average global temperatures to rise by more than 1.5ºC.

Carbon dioxide emissions from buildings occur from two sources: operational carbon and embodied/upfront carbon. Construction, occupation and demolition of buildings are responsible for 39% of global CO_2 emissions. 11% of this is directly attributed to the manufacture of construction materials and components.[121]

Processing and transporting raw materials to create building materials and components requires energy. Most fuels used to generate this energy are carbon-based, resulting in the release of CO_2 and other greenhouse gases to the atmosphere as the fuel is burnt. Mineral, metal and petrochemical building materials tend to require a lot of energy, and result in a lot of CO_2, during their manufacture and processing. Plant-based materials tend to require less processing, so using less energy and resulting in lower CO_2 emissions. The amount of CO_2 emitted during the extraction, manufacture, processing and transport of materials is referred to as its **'embodied' or 'upfront' carbon dioxide**.

Plants used for building materials, such as straw and timber, also absorb CO_2 from the atmosphere through photosynthesis, converting this to carbon (which creates the solid part of the plant), water vapour and oxygen (which are released back to the atmosphere). This conversion and storage of CO_2 is termed 'sequestration'. Lime – used for mortar and render and created by burning limestone with coal – behaves similarly, absorbing atmospheric CO_2 as it sets, or 'carbonates', though it can only absorb the amount of CO_2 that was driven out through the firing process.

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[118] https://www.architecture.com/-/media/files/climate-action/riba-2030-climate-challenge.pdf?la=en
[119] https://www.architecture.com/-/media/files/climate-action/riba-2030-climate-challenge.pdf?la=en
[120] https://www.earthobservatory.nasa.gov/features/CarbonCycle
[121] http://wedocs.unep.org/bitstream/handle/20.500.11822/30950/2019GSR.pdf?sequence=1&isAllowed=y

It is common for plant-based building materials to store more CO_2 than is emitted during its processing, often leading to them being termed ‘carbon negative’. This is an unhelpful term as it provides scope for the use of undesirable, high carbon materials and components in a race to achieve a zero sum game. A more appropriate approach is to acknowledge the carbon sequestration characteristics of some construction materials but aim for a level of upfront carbon emissions that can be safely absorbed within the planetary carbon cycle.

During the lifespan of buildings energy is used to provide heating, cooling, hot water and power. This energy can be generated from a variety of fuels including finite, carbon-rich oil, gas and coal, or renewable sources such as solar radiation and wind. Generation of this energy will result in more or fewer **‘operational’ CO_2** and other greenhouse gas emissions, depending on fuel type. Our objective, of course, should be to eliminate operational CO_2 emissions from buildings entirely – reaching ‘zero operational carbon’. In practice this is achieved by offsetting carbon-rich energy generation with an equal or greater amount of energy from renewable sources – ‘net zero operational CO_2’. The reality of the latter is that CO_2 emissions *have* been generated, and can never be *un-generated*. The most appropriate approach is to minimise operational CO_2 emissions and use local or UK-based renewable sources to generate the amount of energy needed in a low-carbon manner.

Offsetting CO_2 emissions from human activity, including aviation, agriculture, transport and use of buildings is becoming increasingly common. Numerous schemes have developed which treat offsetting as a service of forgiveness, offering to plant trees, construct wind turbines, erect solar panels and improve biodiversity. Rather than reducing CO_2 emissions they attempt to absorb the same amount of CO_2 emitted by the original recklessness. Many are based overseas and are difficult to monitor for effectiveness. If offsetting through a scheme remains the only option it is sensible to make sure it is located in the same region as the project so that its effectiveness can be regularly checked.

The term ‘carbon footprint’ can be used to mean embodied CO_2 or the total amount of CO_2 emissions from a project across its lifetime. This is most accurately calculated by a combination of Whole Life Carbon assessment, for which a number of different methodologies are available. For the purposes of this report it is recommended that the Royal Institute of Chartered Surveyors’ Whole Life Carbon calculation methodology be adopted.[122]

For housing to achieve **carbon efficiency** the following principles must be established:

- The materials and components in existing buildings constitute very large quantities of embodied/upfront carbon. Retention and refurbishment of existing buildings must be prioritised over their demolition to minimise the loss of this embodied/upfront carbon;
- The case for demolition of existing buildings can only be justified where whole life carbon analysis supports this. Non-toxic building components from existing buildings must be re-used;
- Materials and components for refurbishment and new build must be assembled to allow them to be disassembled and re-used in their original state, preventing CO_2 emissions from the manufacture of new materials.

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[122] https://www.architecture.com/-/media/GatherContent/Whole-life-carbon-assessment-for-architects/Additional-Documents/11241WholeLifeCarbonGuidancev7pdf.pdf

- All materials for new build and refurbishment of houses must have very low embodied/upfront carbon. Materials that sequester CO_2 must be prioritised over those that do not. For projects up to 2030, embodied carbon must achieve the LETI (London Energy Transformation Initiative) 2030 target of 300kg CO_2e/m^2 and 200kg CO_2e/m^2 including sequestration[123];
- If offsetting is required it must be achieved within 100 miles of the site to enable monitoring.

6.6 Water

97% of all water on earth is found in the oceans and around 2.5% is locked up in glaciers, and icecaps. Around 0.014% of all the water on earth is available and accessible as fresh water.[124] Like carbon, this water is a finite resource driven in a solar-powered continuous cycle from atmosphere to ground and back to atmosphere.

Water is not distributed evenly around the planet and as many as 4billion people face water scarcity.[125] This is likely to be exacerbated as water use for manufacturing and thermal energy generation is predicted to increase by 55% between 200 and 2050.[126] It is essential that the value of water is understood and that it is used as efficiently as possible to limit the risk of scarcity for others. In some areas climate change is increasing the frequency and severity of flooding, leading to ill-health, loss of life, economic impacts and creation of waste.

After agriculture, industrial processes – including manufacturing construction materials and components - account for the second greatest use of fresh water on the planet. In buildings water can be considered, like energy and carbon, in two ways: **embodied** water, i.e. the water used to manufacture materials, components and buildings (also referred to as 'embedded water' and its 'water footprint'), and **operational** water, i.e. water used every day by occupants for activities like drinking, cooking, cleaning and washing.

It is generally understood that mineral, metal and petrochemical building materials and components use much greater quantities of fresh water in their processing, manufacture than plant-based materials[127]. However, very little work has been undertaken to quantify embodied water in construction materials commonly used in the UK. According to the UK's Construction Products Association "*Methods to measure net freshwater usage for products (an environmental profile) have existed for several decades and have recently been harmonised into a European standard (EN15804) for producing Environmental Product Declarations*."[128] Unfortunately this is a voluntary standard, caused in part by the very low financial cost of fresh water in many regions. As a result no database exists of embodied water in construction products.

Despite this lack of knowledge it is reasonable to assume the following:

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[123] LETI Embodied Carbon Primer: https://b80d7a04-1c28-45e2-b904-e0715cface93.filesusr.com/ugd/252d09_869f0ce2dc8a4a65a1b87890609ede32.pdf
[124] https://en.wikipedia.org/wiki/Water_scarcity
[125] https://advances.sciencemag.org/content/2/2/e1500323?utm_source=TrendMD&utm_medium=cpc&utm_campaign=TrendMD_0
[126] https://www.sciencedirect.com/science/article/pii/S2212371717300458
[127] https://www.sciencedirect.com/science/article/pii/S2212371717300458#bib16
[128] https://www.constructionproducts.org.uk/media/87904/water_efficiency_report.pdf

- Construction products manufactured in countries suffering from water scarcity (e.g. tropical timber from Guinea Bissau[129], where average fresh water availability is 45 litres/person/day[130]) will have a greater negative impact on fresh water supplies than similar products sources from countries that do not suffer from water scarcity (e.g. hardwood from the UK, where average fresh water availability is over 2,600 litres/person/day[131]);
- Building materials and components that are highly processed, such as metals, petrochemical products and mineral-based products, will require more water than those which require little processing, such as plant-based construction materials and components;
- Construction methods that involve assembly of dry, prefabricated components (e.g. solid-timber wall, floor and roof panels) use less water than water-based, on-site construction methods (e.g. in-situ concrete, brick mortar, plastering).

Water used in buildings during their occupation is more widely understood. The average individual consumption of fresh water in Scotland is around 150 litres /day, equating to around 800 million litres / day for the whole country. To encourage water efficiency in homes Building Regulations set limits on water use by toilets and taps. They also set optional standards for enhanced water efficiency of appliances. However, homes in Scotland do not have any daily water use limits, nor – unlike England and Wales – is water consumption metered. Scotland's national water provider for homes, Scottish Water, is one of the biggest energy users in the country[132]. It also estimates water loss through leakages in its systems of around 480 million litres/day[133]. To address the finite and precious nature of fresh water, the RIBA 2030 Climate Challenge sets targets for domestic water consumption.

For housing to achieve **water efficiency** the following principles must be established:

- Housing must be located away from areas of flood risk to minimise potential damage, waste and ill-health;
- Use of highly-processed construction materials manufactured in countries suffering from water scarcity must be eliminated. ;
- Irrespective of geographical source, materials and components with the least amount of processing and dry, prefabricated construction methods, should be specified over highly-processed alternatives, to minimise embodied water;
- Operational water consumption of homes must achieve the RIBA 2030 target of 75 litres per person per day[134].

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129 https://www.reuters.com/article/us-bissau-logging-insight-idUSBREA4K04N20140521
130 https://www.worldwater.org/
131 https://www.worldwater.org/
132 https://wwtonline.co.uk/news/scottish-water-reaches-energy-milestone-
133 https://www.scottishwater.co.uk/en/Your-Home/Your-Water/Leakage
134 https://www.architecture.com/-/media/files/Climate-action/RIBA-2030-Climate-Challenge.pdf

7 Conclusions

"Buildings & the built environment should be at the heart and soul of economic & social policy able to contribute to health, well-being & life chances"

This study began from a point of view of looking at the changes in the construction sector since the construction of the REH2013 in order to inform the construction of a hypothetical REH 2020. It rapidly became clear that changes in global understanding of anthropocentric caused environmental harms outweigh changes in the construction sector in the same period. The research was therefore based on an understanding that the solutions required go far beyond anything envisaged during the design and specification of the REH2013.

7.1 Scope of Considerations

The *"current Net Zero Carbon focus in buildings - the direct carbon from the construction process and the in-life carbon, mainly energy and heat*" [135] is a huge underestimation of the real impacts of buildings and the role that they must play in achieving Net Zero Carbon.

If we are to look to genuinely resource efficient housing for the future then the types of waste and how waste occurs at each stage of the pre-design, design, construction, in-use and end stages of building life is a vital consideration – from inception through to re-use.

Energy policy must seek to target 1-planet living incorporating as far as possible all building, behavioural and societal related waste There are numerous precedents and new initiatives that successfully address scale, density, materials, place, lifespan and targets that should underpin a 2020 housing project and can inform the changes required.

The potential restorative qualities of a well-informed and committed construction industry are enormous.

7.1.1 Materials

It is not sufficient for the quantity of waste **and** recycling to rise regardless of its composition. **Waste must equal a resource (food) for optimal technical recycling.** It is therefore vital to address the nature and quantity of waste streams as an issue rather than as a percentage. Cradle to cradle ready products and materials should be the norm.

Those materials that are known at manufacture to have no future use except as recycled waste must be eliminated from the life cycle in favour of materials that at the end of productive life can be reused until they can return harmlessly to earth. Addressing waste from this perspective would contribute to the availability of all construction materials and products for future use.

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[135] Stephen Boyle ZWS – correspondence March 2020

This requires nothing less than the elimination of all toxins from manufacturing processes because management of waste that cannot be safely returned to earth takes time and energy in perpetuity and presents a burden to future generations. “Hybrid” materials present a particular problem.

All waste streams must also be scrutinised not simply by volume and weight to divert from landfill but to contribute to legally binding net zero targets permanently.

The Polluter Pays Principle – already established in the international domain – should be fully enforced as a life cycle issue. *Circular economy ready* products must become the norm for construction. A small number of organisations in other sectors – such as clothing - are addressing these serious issues seriously and could be useful as *pathfinder* models.

The wastes involved in the remodelling, redecorating and refurnishing of buildings should be incorporated as building related waste and policies directed to reducing it.

7.1.2 Policy

Garnering the current capacity of the mainstream construction sector in Scotland to deliver resource efficient housing will require the use of mainstream devices – industry wide policy, education, training, regulation and planning policy on a large scale –to create the necessary mainstream change.

The importance of the issues needs to be communicated through policy as the drivers of future housing supply across the sector at all levels. Given the timescales for policy, it is vitally important to set the regulatory framework within which zero waste housing can flourish. A legally binding and legible road map to 2035 is required with sufficient ambition (target 2030) to ensure that the target is not missed. There is excellent practice in Scotland that can guide policy.

There are a number of placeholders for future revisions of the Standards and the availability of new knowledge, advanced practice and tools like OneClick and PHPP could now mean that the Standards could be updated.

Some of the biggest challenges will be communicating to mainstream builders, developers, Government and planning the context of contemporary ZW construction.

There is no evidence to suggest that the scale of the required change will happen voluntarily.

7.2 Objectives of a Hypothetical Housing Project

The role of housing and the wider built environment in quality of life is increasingly apparent. Hence, the nature of housing must change:

- To meet the expectations of a 2000 –watt society,
- To minimise waste and pollution of all kinds, at all points in the building life cycle, and
- To both meet human needs and offer responsible stewardship.

This affects location, massing, size, lifetime, supply chains, materials, products, social networks, ecology and user behaviours.

As a consequence of the convergence of these ideas the proposal for our brief is the design and construction of at least 24 new houses and refurbishment of 24 existing houses, located within an existing settlement with medium-quality public transport connections.

The project should engage, inform and educate the public and the sector on the importance and opportunity to eliminate waste and be used to guide policy.

7.3 Future Research Required

1. Set out a legally binding and legible road map to 2035

2. Document best practice housing and prepare training for policy setters and industry.

3. Identify those materials that impose a recycling burden on consumers, government and industries in line with a polluter pays strategy.

4. Seriously address our relationship with imported products and the regulations that require them – such as imported high embodied energy PV panels - that should be open to close scrutiny in terms of their overall global benefit.

5. Work towards distinguishing and better analysing the implications of different forms of waste and the manufacturers responsibilities under Polluter Pays

6. Research the pros and cons of MVHR vs. Natural ventilation in relation to health and climate resilience

7. Create an evidence based future climate data set for energy analysis of future buildings.

8. Identify the impact of a Scottish agriculture and construction manufacturing sector based on cradle to cradle ready products.

7.4 The Regulatory Context

There are numerous references to waste (waste water, fire hazard from waste storage, building on waste ground and recycling).

- Sustainability Silver Aspect 8: Material use and waste requires a dedicated storage space for recycling solid waste: Provide a dedicated internal space with a volume of at least $0.12m^3$ (120 litres) and no dimension less than 450mm, for storing recyclable material.
- Gold Aspect 8 requires storage as for Silver Aspect 8 and Design for de-construction: By consideration of waste minimisation arising from the built-form. It references the SEDA Design for Deconstruction Guide.[136]

These do not as yet address the scale of the materials issues in construction.

The Scottish Governments Building Standards introduced Sustainability in 2011 as Section 7. It has a focus on: energy efficiency, water efficiency.

Section 7 sets out some boundaries for the consideration of sustainability.

- location and transport cannot be adequately delivered by the building standards system;

[136] https://www.researchgate.net/publication/303231874_Design_for_Deconstruction

- material sourcing and embodied energy are considered inappropriate for inclusion in the optional upper levels for domestic buildings due to complexity.

Meeting our legally binding targets mean that these goalposts need to move. Climate emergency and resource depletion now necessitate augmentation to support net zero. New knowledge, emerging concepts and best practice allow for updating of existing Section 7 placeholders.

7.5 Summary of Recommendations for Zero Waste Scotland

- R1. extend its remit to work closely with manufacturers to stop creating waste and ensure that new materials and products are not ultimately to become waste due to inappropriate chemical transformation or composition.
- R2 work with Creative industries and Agriculture to identify, support and utilise benign, safe building products i.e., Specify what is waste at manufacture rather than end of pipe and concentrate more on supplier systems change and less on recycling
- R3. work with Building Standards to update the regulations to include waste minimisation. This particularly applies to Section 1 (structural design), Section 3 (environment), Section 6 (energy) and Section 7 (sustainability). There is significant scope for existing sections to include, for example, embodied energy and carbon, and design of buildings for long life and flexible use. The availability of tools like OneClick and PHPP could now mean that the placeholders for future revisions can now be updated.
- R4. support full enforcement of The Polluter Pays Principle extended Producer Responsibility as a life cycle issue for all products.
- R5. work with other organisations to add and embed zero waste into best practice construction excellence criteria - SWMP/ CEEQUAL Considerate constructors, BIM
- R6. to work with trades bodies and government to establish a Training course for all on site workers. This could complement, for example, existing site training schemes such as CSCS and form part of normal site induction procedures.
- R7. work with legislators, planners, developers and builders to update the legal framework to establish the basis of a 1-planet target.
- R8. work with Building Standards to update the regulations to take account of decarbonised electricity in determining best options for energy generation.
- R9. work with planning to incorporate a Biotope factor into all new development
- R10. engage with the new green deal.
- R11. support Professional Standards that abide by Circular Economy Principles
- R12. focus heavily on the benefits of refurbishing existing buildings, helping to drive ambitious and binding standards for retrofit that meet the same waste- and pollution-preventing aspirations as new-build.
- R13: promote an exhibition and design competition based on the brief in this report to deliver genuine resource efficient housing appropriate to the Net zero by 2045 challenge – to include behaviour, size, location, massing etc. A unit of 24 homes is used as a starting place for the purpose of the study.
- R14. promote develop and support a student construction project to engenders skills and knowledge in students to help them deliver this in practice as a matter of course. This could be along the lines of:

i. Students across all construction disciplines and all years collaborate to
   - design and optimise,
   - construct and optimise,
   - occupy, monitor and optimise and
   - disassemble and evaluate a small building.

ii. Projects need not be large, complex or expensive. [137]

iii. This would involve creating and taking apart the same components over and over again, establishing where waste occurs, where new components work, which ones can't take much re-use, understanding how to reduce waste to zero, and understanding which cycles waste fits into.

iv. The potential for inter-department collaboration with e.g. health, arts, geography, maths, engineering, digital skills should be encouraged.

[137] The CASS has just won an AJ Small Projects award for a £10k studio they built for themselves. https://www.ajbuildingslibrary.co.uk/projects/display/id/8376

8 Closing Comments

If we seek to "produce a building to the highest building standards using methods which would keep waste to a minimum and use reused materials wherever possible" and "…… to influence volume builders." Then there are some fundamentals that require to be embedded.

8.1 Best Practice

A range of skill and knowledge are required to successfully innovate. This starts with a review of existing best practice – success and failures – in order to be well informed.

Numerous pertinent high performance projects, guidance and initiatives can be identified in Scotland and further afield. That are exceeding the standards e.g., air tightness and addressing other resource efficiency strategies such as using bio-materials for sequestration and calculating and comparing embodied energy - albeit roughly. Many of those meeting higher than building regulatory are doing so as part of a broader environmental agenda often using moisture transfusive construction, giving high importance to airtightness detailing, airtightness testing, thermal bridging, indoor air quality and excluding non-environmentally friendly materials. Layering was is an increasingly well-recognised low impact construction technique.

Best practice in resource efficiency in the built environment in other countries could inform also. Many surpass current regulatory requirements and importantly look at a much wider range of resource, waste, as well as, social issues. Numerous countries are exploring ideas of resource sufficiency to address environmental constraints and the role of design in influencing behaviour to deliver efficiencies beyond what regulated emissions can achieve. Some of these are documented in Section 3. This best practice had potential to influence policy.

- **The opportunities offered by existing best practice needs to be better communicated to government, research and industry.**

8.2 Information

The industry would benefit from a discussion about a design approach to transport, landscape, construction that can contribute to one planet living, miigate environmental impacts and allow us to live well.

It would also be helpful to clarify the potential impacts of design solutions with more data. Embodied energy, local energy generation are crucial components of zero waste strategies, and data helps to ensure that the most appropriate strategies are selected.

Defects and maintenance strategies should also be a part of construction strategy –s cold bridging, condensation or mould, technology or services.

POE could provide valuable sources of information on airtightness, thermal imaging, overheating, energy in use, indoor air quality for an industry that needs to develop rapidly to meet enhanced performance targets.

- **POE remains a requirement for all buildings in order to eliminate the performance gap.**

8.3 Air tightness

There is an ongoing issue with skills and traceability wrt air tightness and air tightness testing. There is also a widely held belief that performance testing requirements are grossly inadequate to guarantee targets are achieved. Only one in twenty houses are required to be tested and this is largely at the discretion of the contractor. Worryingly there is a significant concern that the costs of remedying inherent failings mean that fake results might be bought cost effectively.

If true then this suggests that not only must regulations and evidence gathering tighten but that a sea change in attitude of constructors is required if widespread corruption is to be avoided and undermine positive efforts to meet net zero targets.

"12 steps to air tightness" is a well recognised training programme .[138] It recognises the need for constant vigilance and the experience of a trained Clerk of Works.

- **Air tightness targets remain a significant problem in Scotland and a full training scheme should be established immediately that embraces indoor air quality issues including natural ventilation strategies.**

8.4 Off-site Construction

A highly efficient emerging aspect of construction is off site prefabrication. This minimises construction waste and greatly optimises the speed of construction. Cross Laminated timber and Brettstapel construction[139] have both been applied successfully in Scotland

- **The benefits of modular construction are significant and steps are required to progress its development by liaising with existing best practice.**

8.5 Low carbon Technologies

Some recent, new and emerging technologies require to be fully analysed for their genuine benefit. For instance it is now highly likely that the decarbonisation of the Scottish Electrical grid makes it more appropriate in global terms than using high-embodied energy imported goods for energy generation. There is also now much more concern about overheating.

- **Identify the most appropriate technologies based on carbon dioxide payback**

8.6 Local Energy Generation

In respect of local energy generation an option appraisal would generally be required to assess the best balance of capital cost, cost in use and lifetime. Issues around local energy generation are however, complex.

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[138] https://www.aecb.net/download/delivering-airtight-buildings-12-step-program-2/
[139] http://www.brettstapel.org/Brettstapel/Home.html

- **There remains a requirement with building standards to generate energy locally however evidence emerging suggests that this may not be the most resource efficient approach in the global context where the Scottish grid is largely decarbonised.**[140,141]

8.7 Deconstruction Strategy

New technology such as BIM could be a mechanism to manage the data exchanges required to embed design for deconstruction but skills enhancement at all level will be required. Trade groups such as PHPP and AECB lists are potential mechanisms for upskilling, although ideally all architects and construction professionals.

- **Better information on issues around future use and value of new and recycled materials, products and components is required.**

8.8 Materials

Low embodied energy materials deployed in structurally sound ways are preferred to high-embodied materials. There is increasing recognition that we no longer have time to recoup upfront (embodied) energy, hence buildings need to be sequesters of carbon and storehouses of future resources and value. This is likely to be the future norm. Where high-embodied energy materials are considered then we need innovative tools and techniques - such as the rapidly evolving use of One Click and BIM to compare options.

The lack of adequate CE marking on many recycled goods makes them unacceptable to the volume builders.

Material passports and BIM offer potential to provide traceability and to register inherent value of all building components.

- **More information is required on impacts of material – both virgin and used and technology needs to embed material recognition in building information.**

8.9 Replicability

Replicability is often sought to introduce cost savings but can create a difficult combination of demands. Individual touches, rather than ‘replicability’ could be a valid response to resource efficiency.

- **Where aspects of replicability add value then they should indeed be sought but where an over obsession with replicability brings problems then it should be acknowledged as unhelpful.**

[140] Atkins R (2020) **Let’s Talk About Numbers** RIAS Journal
[141] The Scottish Greenhouse Gas Emissions Annual Target Report for 2017

8.10 Volume Builders

The current dominat detached building model introduces inefficiencies and makes it largely inappropriate for any Scottish context urban, suburban or rural. Placemaking needs to recognise the role of location, massing, orientation, behaviour, mixed use living and post occupancy appraisal in a truly resource effective, circular economy society.

There are wide ranging approaches shown in the case studies that might allow us to mitigate our impacts and live well. These seek to address resource effectiveness - of land, money, materials, energy and water – minimise pollution – from transport and transport infrastructure, materials, energy - support healthy living and communities and enhance biodiversity.

- **We need to look to identify best practice, how it has been delivered and offer sensible stewardship to create housing for the future.**

9 Resources

9.1 Guidance

i. Liddell HL, Kay T & Stevenson F. (1994) New From Old: The potential for reuse and recycling in Housing Scottish Homes

ii. Halliday S.P and Pemberton G (2001) Scottish House: A Review of Recent Experience in Building Individual and Small Groups of Houses with a View to Sustainability, the Use of Traditional and New Materials and Innovative Design. Scottish Executive

iii. Halliday S.P 2003 Urban Ecology: module 15 – Sustainable Construction CPD Series Gaia Research

iv. Morgan C & Stevenson F., (2005) Design and Detailing for Deconstruction **-** The Scottish Ecological Design Association

v. Compiling best practices, and sets of replicable details. It was included as a reference document in the Scottish Building Regulations in 2011 when Section 7 – Sustainability was added.

vi. Gilbert J., Halliday S.P, Liddell HL. (2008) Design and Detailing for Toxic Chemical Reduction in Buildings **-** Scottish Ecological Design Association

vii. Compiling best practices, and sets of replicable detail about how to specify non-toxic materials in buildings.

viii. Halliday S.P (2018) Sustainable Construction 2nd Ed. Butterworth Heinman

ix. Sections covering precedent, policy, design appraisal, energy, health & well being and process factors including 120 case

x. Atkins et al (2018100 Sustainable Scottish Buildings) SEDA

xi. Morgan C., (2018) Sustainable Renovation in Practice SEDA & the Pebble Trust

xii. Halliday S.P, Foster S (2019) Scotland's Housing – More than just Numbers Gaia Group

xiii. Scottish Ecological Design Association website contains text and films related to sustainable community housing concepts

xiv. https://www.seda.uk.net/new-blog/zxb22hbp8ee4lb7ulfr7a9bwo6lq73

9.2 Additional Bibliography

i. Aitchison M (2018) Prefab Housing and the Future of Building: Product to Process. Lund Humphries.

ii. Baker –Brown D (2017) The Re-use Atlas RIBA Publishing

iii. Brand, S. (1994) How Buildings Learn. Viking

iv. Berge, B. (1999) Ecology of Building Materials 2nd Ed. Architectural Press

v. BRE Trust (2013) Dealing with difficult demolition wastes: A guide

vi. Bowman C RIAS Quarterly

vii. Brown M (2016) Futurestorative: Working Towards a New Sustainability. RIBA Publishing.

viii. Centre for Alternative Technology (2019) Zero Carbon Britain: Rising to the Climate Emergency. Available: https://www.cat.org.uk/info-resources/zero-carbon-britain/research-reports/zero-carbon-britain-rising-to-the-climate-emergency/

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x. Commoner B. (1970) The Closing Circle Knopf

xi. Ellen MacArthur Foundation (2016) Circular economy in India – Rethinking Growth for long term prosperity Ellen MacArthur Foundation

xii. Ellen MacArthur Foundation (2016) Circularity in the built environment – a compilation of case studies from the CE100 The Ellen Macarthur Foundation

xiii. Forestry Commission Scotland (2010) Materials Considerations – A Case Study 04 Acharacle School Sust

xiv. Forestry Commission Scotland (2010) Materials Considerations – A Case Study 09 Glentress Peel Sust

xv. Gaia Group (2005) Design & Construction of Sustainable Schools, Vols 1 & 2. Scottish Executive. www.gaiagroup.org

xvi. Halliday S.P (2018) Sustainable Construction Routledge

xvii. Halliday S.P. et al (2005) Affordable Low Allergy Housing Gaia Research

xviii. Halliday S.P & Atkins R (2016) The Sustainability Guide to the Plan of Work 2013 RIBA Publishing

xix. James M & Bill J (2016) Passive House in Different Climates Routledge

xx. King B (2017) The New Carbon Architecture: Building to Cool the Planet. New Society Publishers.

xxi. Heede R. (2014) Tracing anthropogenic carbon dioxide and methane emissions to fossil fuel and cement producers, 1854-2010. Journal of Climatic Change.(2014) 122:229–241 open access http://carbonmajors.org/download-the-study/

xxii. IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. In Press.

xxiii. Liddell H.L ((2013) Eco-minimalism – the antidote to Eco-bling 2nd edition RIBA Publishing

xxiv. London Energy Transformation Initiative (2019) Net Zero Operational Carbon. Available: https://www.leti.london/

xxv. McDonagh W & Braungart M (2008) Cradle to Cradle: Remaking the Way we make things Vintage books

xxvi. Rathje W., (1991) Once and Future Landfills, *National Geographic,* May

xxvii. Rathje W., (1992) Rubbish!: The Archaeology of Garbage, New York: Harpercollins, 1992. ISBN 0-06-016603-7

xxviii. Rathje W., (1998) Use Less Stuff: Environmentalism for Who We Really Are, with R M Lilienfeld, New York: Ballantine Pub. Group, 1998. ISBN 0-449-00168-7

xxix. Rathje W., (2004) The Perfume of Garbage: Modernity and the Archaeological Modernism/Modernity*.* 11. 1 (2004): 61–83.

xxx. Reeder L. (2016) Net Zero Energy Buildings Routledge

xxxi. Roalkvam D. & Berge B (2014) Absolute Passive Energy Design Gaia

xxxii. SEDA Design Guides - https://www.seda.uk.net/design-guides

xxxiii. Design & Detailing for Toxic Chemical Reduction

xxxiv. Deign & Detailing for Deconstruction

xxxv. Design& Detailing for Airtightness

xxxvi. Improving Homes for Energy, Health and Environment – Sustainable Renovation

xxxvii. Short C A (2017) *The* Recovery of Natural Environments in Architecture Routledge

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xxxix. Weismann A Bryce K. (2008) Using natural finishes: lime and clay based plasters, renders and paints. Totnes, Green Books.

9.3 Topic Specific References On Line

9.3.1 Design for Deconstruction

i. BRE, with funding provided by the BRE Trust and Zero Waste Scotland developed an outline methodology to measure the ‘deconstructability’ of new build residential buildings with applicability across all the new build.

ii. https://www.bregroup.com/buzz/design-for-deconstruction-helping-construction-unlock-the-benefits-of-the-circular-economy/

9.3.2 Health & Well Being

i. https://www.theguardian.com/society-professionals/2014/aug/08/housing-problems-affect-health.

ii. Howieson S., https://pureportal.strath.ac.uk/files-asset/71287505/Howieson_Sustainability2017_The_great_Scottish_housing_disaster_the_impacts_of_feudalism_modernism.pdf

iii. http://www.iaquk.org.uk/

iv. https://www.architecture.com/riba-books/books/construction-engineering-and-surveying/product/hazardous-building-materials-a-guide-to-the-selection-of-environmentally-responsible-alternatives.html

9.3.3 Material Sourcing

i. The materials section at www.greenspec.co.uk.

9.3.4 *Embodied Energy*

i. A 2018 overview of methods:
ii. https://www.sciencedirect.com/science/article/abs/pii/S0378778817327937
iii. RIBA Whole Life Assessment
iv. https://www.architecture.com/knowledge-and-resources/resources-landing-page/whole-life-carbon-assessment-for-architects
v. Thornton Tomesetti - Beacon
vi. https://www.thorntontomasetti.com/beacon_embodied_carbon_measurement/
vii. Inventory of Carbon & Energy
viii. http://www.circularecology.com/embodied-energy-and-carbon-footprint-database.html
ix. ASBP/Makar example
x. https://asbp.org.uk/wp-content/uploads/2016/07/MAKAR-Carbon-Measurement-ProjectFinal3.pdf
xi. Wood Knowledge Wales Example
xii. http://woodknowledge.wales/uncategorized/clwyd-alyn-housing-project-exceeds-riba-2030-climate-challenge-target

9.3.5 Useful Organisations

i. **ASBP: Alliance for Sustainable Building products** - https://asbp.org.uk/

Produce information on benefits and limitations of low impact building materials.

ii. Bioregional / One Planet Living - https://www.bioregional.com/one-planet-living/

BIoR / the OPL framework comprises of ten principles, detailed goals and guidance.
Buildings As Material Banks (BAMB) - https://www.bamb2020.eu/

iii. BAMB brings people together to create circular solutions that increase the value of building materials, including enabling materials to sustain their value, reduce waste and use fewer virgin resources:

iv. Building with Nature Standard - https://www.buildingwithnature.org.uk/

Building with Nature provide a framework of quality standards, an assessment and accreditation service, and national awards recognising the design and delivery of high quality green infrastructure.

v. Global Footprint Network - **https://www.footprintnetwork.org/**

The Network's activities revolve around calculation and dissemination of the Ecological Footprint. The Footprint measures human demand on nature, expressed as a single, easy-to-understand number that's scalable from an individual to a global level. Our Footprint data and tools empower leaders at the local and national level to make confident policy and investment decisions backed by facts.

vi. **GreenSpec**:- www.greenspec.co.uk *promotes sustainable building products, materials and techniques. It is Independent of companies and trade bodies and edited by practising architects and specifiers - ensuring that the content and communication style is responsive to the needs of both design professionals and the self-build audience.*

vii. **International Living Futures Institute -** https://living-future.org

The Institute runs the Living Building Challenge Award, for demonstrable net-positive buildings, covering materials, resources, communities and health and well-being

viii. **LETI** https://www.leti.london/cedg

The London Energy Transformation Initiative (LETI) published a Climate Emergency Design Guide in 2020, detailing how to go about designing and delivering carbon zero new buildings: this is an ever-growing resource, and includes aspects such as a cross-industry definition of Net Zero Operational Carbon.

ix. The **RIAS**: Accreditation Scheme in sustainable design

https://www.rias.org.uk/for-the-public/sustainability

x. **The RIBA** published its Sustainable Outcomes Guide, detailing how to go about delivering carbon zero buildings by 2030, in line with its 2030 Challenge.

xi. **Living Building Challenge Red List** - http://living-future.org/redlist

A list of chemicals and compounds known to be toxic to human health that ideally should be removed entirely from both the built environment and the supply chain.

xii. **National Recycling Forum** - https://nra.mrw.co.uk/

NRF finds, recognises and celebrates those making a difference in the recycling and waste management industry

xiii. Waste and Resources Action Programme: www.wrap.org.uk

WRAP works to achieve a circular economy, helping reduce waste, develop sustainable products and use resources in an efficient way.

xiv. **Wastebuild**[142] is now an independent forum for waste minimisation in construction.

[142] https://www.wastebuild.com/

10 Project Team

gaia group

- **Professor Sandy Halliday BSc (Hons) MPhil CEng MCIBSE Hon FRIAS -** Project Lead Consultant

Sandy is a chartered engineer and highly respected author and communicator with extensive experience of research and inter-disciplinary working. She has worked as a researcher and a teacher on environmental issues and as a sustainability adviser to private, public and third sector organisations since 1986. Her degree in Engineering Design & Appropriate Technology (1985) focused on socially and environmentally responsible engineering. Sandy initially worked in design of socially useful products. She moved into the building services sector as a research manager to develop & disseminate information on environmental issues, passive design, waste management, resource efficient & clean technologies, healthy buildings, and benign construction processes, products & materials.

- **Samuel Antony Foster BSc, BArch (Hons) Dundee** - Research Consultant

Sam is Scotland's best practicing ecological building professional with vast experience at the forefront of design. Having built his Part 3 experience with Gaia he has gone on to be Project Architect on exemplar low impact projects Acharacle, Plummerswood and Glentress. He has developed a portfolio of work around low impact design and healthy materials and developed a reputation as a community architect. He is a regular contributor to events on materials, energy and health and well-being. He takes a passionate interest in the circular economy in building design and is a qualified passive house consultant.

- **Karl Hutchison** - Research Subcontractor

Karl is a senior lecturer at the University of the West of England and Lead Architect with Agile Design. His PhD focused on self-help movements with the context of sustainable cities and this interest has shaped his architectural project work. Karl has been lead on a variety of sustainable schemes from the award winning 12 Eco-homes at Great Bow Yard, Langport in 2008 to the LILAC co-housing scheme in Leeds and Gagle Brook Zero Carbon School in Bicester Eco-town completed in 2016.

Thanks are also due to :-

- **Craig White** BSc, Architectural Studies. Architectural Association AA Dip, FRSA.

Craig is an experienced leader and company director in the private sector with non-executive director roles and board level experience for organisations in the design, construction, charity, research and arts sectors.

- **Scott MacAulay** BSc.Hons. Architectural Studies PGD Ad Arch Design

Scott is a Part 2 Architectural Designer with a specialisation in healthy, minimal-carbon materials and a committment to employing ecological construction techniques. Scott founded the Anthropocene Architecture School (2019) where he is bringing together students and practitioners to address climate and resource emergency issues in interactive workshops.

- **Kathryn Robinson** BA(Hons) Architectural Design, B Arch, ARB

Kathryn Robinson was the project architect for Glentress and provides research assistance on materials, specification and design detailing for a wide variety of projects.

"Everything Must Go Somewhere"

Barry Commoner