



How can small architectural practices in Wales be encouraged to adopt more sustainable design for domestic projects?

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Abstract

This dissertation discusses how small architectural practices in Wales can be encouraged to adopt more sustainable design for domestic projects. In order to do this, firstly this dissertation explores the Royal Institute British Architects (RIBA) 2030 Climate Challenge, which is a new initiative that looks to promote sustainable design in the UK to RIBA registered architecture practices.

To understand what is meant by sustainable design, this dissertation will examine two types of sustainable design approaches, exploring their principles, and what makes the two methods different. This dissertation also researches types of legislation that can impact on the decision to adopt sustainable design approaches.

To help understand the benefits of sustainable design compared to standard design, four case studies were select of a domestic nature. The results from the case studies show that there is a dramatic reduction of CO₂ emissions when using sustainable design when compared to standard construction on both new builds and extensions, which prompts that more projects should be sustainable; this can be achieved with a little more consideration into the design.

The data collected was analysed and used alongside the 2030 Climate Challenge and UK legislation. From the research it was determined that the 2030 Climate Challenge does not go far enough to promote sustainable design as it only impacts RIBA practices, furthermore, the research on UK planning legislations focusing primarily on Welsh legislation determined the system is currently too complicated and does not allow for different interpretation by individuals.

Finally, the conclusion, makes recommendations on how better promotion of sustainable design can be achieved. More education is required with in the domestic sector to dispel the stigma attached to sustainable design and its affordability and buildability. Additionally, new simpler legislation would be beneficial.

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List of Acronyms

Acronym	Meaning
RIBA	Royal Institute of British Architects
UK	United Kingdom
CCC	Committee on Climate Change
GCB	Green Construction Board
MVHR	Mechanical ventilation with heat recovery
GSHP	Ground source heat pumps
ASHP	Air source heat pumps
WSHP	Water source heat pumps
PV's	Photovoltaics
NPPF	National Planning Policy Framework
PPW	Planning Policy Wales
TAN	Technical Advice Notes
LDP's	Local Development Plans
LPA	Local Planning Authorities
CO ₂	Carbon Dioxide
ACE	Architects Council of Europe
PIR	Polyisocyanurate

Declaration



Author's Declaration

I declare that the work in this dissertation was carried out in accordance with the regulations of the University of Wales, Trinity Saint David. The work is original except where indicated by special references in the text and no part of the dissertation has been submitted for any other degree.

Any views expressed in the dissertation are those of the author and in no way represent those of the University of Wales, Trinity Saint David.

The dissertation has not been presented to any other University for examination either in the United Kingdom or overseas.

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Signature: Gareth William Lawrence

Date: 20/06/2020

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This dissertation is dedicated to all my family and friends.

Introduction

The objective of this dissertation is to explore how small architectural practices in Wales can be encouraged to adopt more sustainable design for domestic projects.

According to a 2019 report published by the Architects Council of Europe (ACE) there were 7,515 architectural practices in the UK in 2018¹. Out of those 3,847 are Royal Institute of British Architects (RIBA) registered². For the purpose of this dissertation the authors research will be focusing on small architectural practices which are defined as: practices that have 1 – 10 members of staff, as stated by the RIBA in the *RIBA Chartered Practice, Accreditation Criteria and Standards, Standards and Enforcement Procedures*³.

An industry commentator believes that the topic of sustainable design has become controversial among academics, commentators, architects and contractors etc.⁴. This is because there are many different interpretations of what sustainable design means, although in most cases they are very similar, for example:

- 1) Sustainable design is a philosophy of design applied to objects, machines, industrial processes, the built environment, etc., aimed at ecological, resource, economic, and social sustainability⁵.
- 2) Sustainable design embraces a commitment to design the urban environment, factories, public and private buildings, spaces, products, and services in ways that respect the principles of social, economic, and ecological sustainability as a means of counteracting the negative dimensions of traditional design, production, and consumption⁶.

This dissertation will approach sustainable design as a way in which a building can be designed to reduce or eliminate their CO₂ emissions in order to help reduce the construction industries impact on climate change⁷. Furthermore, this dissertation will

¹ (Architects Council of Europe, 2018)

² (Royal Institute of British Architects, 2020)

³ (Royal Institute of British Architects, 2019)

⁴ (Welch, 2020)

⁵ (Escudier & Atkins, 2019)

⁶ (Woodham, 2016)

⁷ (Committee on Climate Change, 2019)

research the use of both passive and active design principles to achieve this reduction. (See Chapter two for definitions and underlying principles).

Due to climate change and the increasing number of individual houses, extensions and loft conversions⁸ (which for the context of this dissertation will be known as domestic projects) being carried out in the UK, there is a need to adopt more sustainable design principles in order to minimise CO₂ emissions, which have been linked to greenhouse gases, global warming and climate change⁹. This makes promoting sustainable design on domestic projects important. The intent of this dissertation is to identify how sustainable design is currently being promoted and what can be done to encourage small architectural practices in Wales to adopt more sustainable methods, on domestic projects, and what more can be done to promote it further. The biggest hurdle to overcome is the stigma attached to a lack of education when it comes to buildability and affordability of sustainable design compared to standard construction^{10, 11}.

The ACE report¹² estimates that the value of the UK's architectural market was €2.3 billion in 2018. Individual houses, extensions, and loft conversions (domestic projects) make up 49% of the type of construction projects carried out in the UK; the breakdown for refurbishment and new build was 59% and 41% respectively¹³. (See Appendix A1 for breakdown of types of jobs carried out in the UK).

For the context of this dissertation, a domestic client is anyone who has construction work carried out for them that is not done in connection with a business. These works are usually done on their own home or a home of a family member¹⁴, as defined by the Health and Safety Executive.

⁸ (Construct UK Ltd, 2020)

⁹ (Committee on Climate Change, 2019)

¹⁰ (Anon., 2017)

¹¹ (Bergman, 2012)

¹² (Architects Council of Europe, 2018)

¹³ (Architects Council of Europe, 2018)

¹⁴ (Health and Safety Executive, 2020)

Climate Change

As previously mentioned, due to climate change, there is an increasing need for architects to use a sustainable approach when designing a project. This is because climate change is affecting the planet more and more every day¹⁵. Research shows that the Arctic and Antarctic Polar caps are melting more rapidly which is leading to rising sea levels¹⁶. Not only this, the frequency and strength of storms are increasing, which is causing considerable amounts of destruction, leading to loss of lives in more severe cases. There is also a shift in rainfall patterns, causing devastating droughts and floods all over the world¹⁷.

Billions of people around the World struggle daily to cope as the climate breaks down, of which the poorest are the hardest hit. Over the last decade there have been more powerful cyclones which have devastated the lives of millions of people in the Philippines. There has been an influx of forest fires in Russia, Europe, America and Australia, which has covered cities in thick polluting smoke¹⁸.

Climate change is causing the atmosphere to warm up, and is creating drier, hotter circumstances in which wildfires can rage out of control, reducing mighty forests to ash around the World. It is also causing the oceans to warm and the water to become more acidic, and in turn is causing mass coral to die-off and destroying the ecosystems of various sea life. On land delicate ecosystems are being lost that are home to insects, plants, and animals as they struggle to adapt quick enough to the changing climate, which is putting many species at danger of extinction. Due to this food security, health, and quality of life are all threatened by the impact of climate change¹⁹.

¹⁵ (Green Peace, 2020)

¹⁶ (Green Peace, 2020)

¹⁷ (Shuckburgh, 2020)

¹⁸ (Green Peace, 2020)

¹⁹ (Green Peace, 2020)



*Figure 1 Image showing flooding in Somerset, winter 2014
(ITV News, 2014)*

Over the last decade the UK has suffered the impact of climate change. Floods turned lives upside-down in Somerset in 2014, and in both York and Leeds in 2015. In addition, the heatwave in 2018 was attributed to the Saddleworth Moors fires which burned for days on end, and left farm crops across Surrey, Kent and East Anglia dry for weeks at a time. Not only this, climate change is affecting UK wildlife like the puffin population which has dropped from 33,000 to 570 over the last 20 years²⁰.



*Figure 2 Image showing Firefighters tackle the wildfire on
Saddleworth Moor 2018
(Independent, 2018)*

²⁰ (Friends of the Earth, 2020)

UK Architects responses to Climate Change

In June 2019, the UK became the first major economy in the World to pass laws to end its contribution to global warming by 2050. Under this law, the UK has set the target to reduce all greenhouse gas emissions to net zero* by 2050, compared to the former target of at least 80% reduction from 1990 levels. So far the UK has achieved 42% reduction in emissions while the economy grew by 72%; this is due to putting clean growth at the heart of our modern Industrial Strategy²¹.

This dissertation will be focusing on net zero* carbon operational energy, meaning the quantity of CO₂ emissions linked with the annual energy use of an operational building will be zero or negative. Net zero buildings tend to be extremely energy efficient and are typically powered by on-site and off-site renewable sources, with the remaining CO₂ balance being offset²², as stated by the UK Green Building Council (GBC) in the *Net Zero Carbon Buildings: A framework Definition*. For the purpose of this dissertation net zero will refer to achieving an equilibrium between emissions produced and emissions taken out of the atmosphere²³.

Following this law, on the 29 June 2019, RIBA Council elected to join the global declaration of an environment and climate emergency²⁴.

The climate emergency demands urgent action from every individual, business and business sector²⁵; the construction industry is one such sector, which is known to contribute emissions, such as CO₂, which are harmful to the planet. Currently there are around 29 million homes in the UK; not only this, the UK Government is committed to allowing 1.5 million new homes by 2022 to be built²⁶.

It is important that action is taken now by the construction industry to deliver net zero in advance of any future regulation on new and retrofit buildings. A recent Green Construction Board Buildings Mission 2030 report informs that net zero CO₂ emission, when it comes to operational use of a building is already, possible. The challenge now for the architectural profession is to extend this practice to all future work²⁷.

²¹ (UK Government, 2019)

²² (Twinn, et al., 2019)

²³ (Anon., 2020)

²⁴ (Committee on Climate Change, 2019)

²⁵ (Committee on Climate Change, 2019)

²⁶ (Committee on Climate Change, 2019)

²⁷ (Royal Institute of British Architects, (2019))

Research Aims and Objectives

This dissertation discusses how small architectural practices in Wales can be encouraged to adopt more sustainable design approaches to reduce or eliminate CO₂ emissions for domestic projects. Furthermore, this dissertation will look at the types of design approach available, and what is currently being done to promote sustainable design, by researching UK legislation and other methods of promotion.

Objectives:

1. Critically review subject literature in the form of legislation, reports, journals, and other initiatives that look to encourage and promote the use of sustainable design in the UK and explore their impact on the domestic market.
2. Review subject literature on the types of sustainable design available and identify their principles and what makes them different.
3. Use a case study approach to compare and analyse a number of domestic projects which have adopted either a sustainable design or a standard design approach in both new builds, extensions and refurbishments to analyse if by using sustainable design principles CO₂ emissions can be reduced and if there are large cost implications involved.
4. This dissertation discusses how small architectural practices in Wales can be encouraged to adopt more sustainable design for domestic projects.

Dissertation Structure

Chapter one explores how the RIBA are encouraging sustainable design among architects; this comes in the form of the 2030 Climate Challenge. By looking at the background of this Challenge it can be understood why its inception has been deemed crucial to help architects to adopt and develop more sustainable design solutions in the UK. Chapter one also identifies what the Climate Challenge targets are, with the aim to reduce the greenhouse emissions to net zero by 2050²⁸.

²⁸ (Royal Institute of British Architects, 2019)

Chapter two looks at two types of sustainable design approaches: passive design and active design. By identifying the key principles of these two approaches it can be understood that there is a clear distinction between the two. As much as these two design approaches are different, this Chapter also explores whether the use of each approach in conjunction with the other will help a building reduce its CO₂ emissions.

Chapter three looks at building legislation in Wales, as it plays a key role in how buildings are designed which can impact on the ability to promote sustainable design to a domestic client. There are a number of different legislative documents that are a prerequisite when dealing with the design of a building, most of these documents need to be read in conjunction with one another.

Chapter four explores the methodology of the chosen approach of data collection through case studies; the data collected will be used to examine the use of a sustainable design approach on domestic jobs compared to a standard building design approach.

Chapter five identifies the selected case studies, and uses the information obtained to fill out the data matrix set, as outlined in the previous Chapter. With the completion of the data matrix, this Chapter will expand on each of the case studies in order to provide more context for the data.

Chapter six analyses the findings from research into two different sustainable design approaches, known as passive and active design principles. Thereafter, the case studies used in the previous Chapter will be examined. Chapter six will also use the findings to examine the use of sustainable design principles on a new build house, and an extension with refurbishment work to an existing house and compare them to similar properties which are of standard design. The analysis will be used to examine the impact on the yearly CO₂ emissions for each situation.

Chapter seven draws together a conclusion from the research undertaken in this dissertation. It will also look to make recommendations on how sustainable design could be better promoted to small architectural practices in Wales. Chapter seven also looks to identify future areas of research that can be carried out to help encourage small architecture practices in Wales to use of sustainable design on small domestic projects and that of large-scale residential developments.

Chapter 1: RIBA on Climate Challenge

Chapter one explores how the RIBA are encouraging sustainable design among their members; this comes in the form of the 2030 Climate Challenge. By looking at the background of this Challenge it can be understood why its inception has been deemed crucial to encourage architects to adopt and develop more sustainable design solutions in the UK. This chapter also identifies what the Climate Challenge targets are with the aim to reduce the greenhouse emissions to net zero by 2050²⁹.

Background

In 2019, as a result of a vote by the RIBA to join the global declaration of an environment and climate emergency, the RIBA launched the 2030 Climate Challenge, which RIBA Chartered. However, this is not mandatory; furthermore, the 2030 Climate Challenge is aimed at RIBA members only. The RIBA voted to join this declaration as a consequence of the UK Government passing amendments to the Climate Change Act 2008, which requires the UK to end its contribution to global warming by 2050.

Through the Climate Change Act 2008, the UK Government has set the target of reducing greenhouse gas emissions by 100% of the 1990 levels (net zero) by 2050. This target of 100%, was founded on the advice given to the Government from the Committee on Climate Change (CCC's) Report *'Net Zero – UK contribution to stopping global warming'*³⁰.

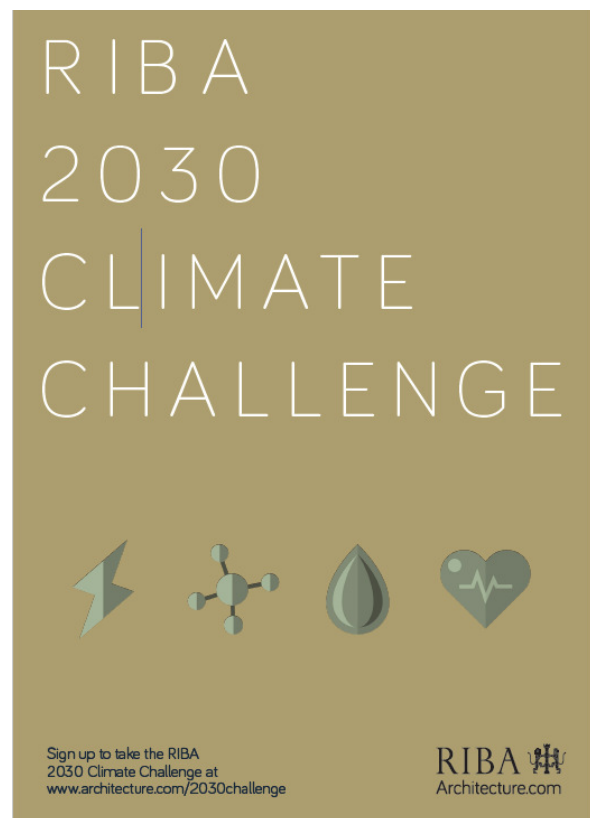


Figure 3 RIBA 2030 Climate Challenge Front Cover (Royal Institute of British Architects, 2019)

²⁹ (Royal Institute of British Architects, 2019)

³⁰ (Committee on Climate Change, 2014)

Following the RIBA agreeing to join the global declaration of an environment and climate emergency, the RIBA President. Ben Derbyshire, stated:

The climate emergency is the biggest challenge facing our planet and our profession. But to have a significant impact we need to do more than make symbolic statements - we need to turn warm words into impactful actions. The implementation of a five-year action plan we have committed to today will ensure we are able to benchmark change and evaluate the actions that make most impact³¹.

Following this statement, the RIBA felt that the current climate emergency required more urgent actions, and that the target of net zero should be achieved by 2030 rather than the UK Government target of 2050. They also felt that direction was needed from architects and the construction industry as a whole; by acting now in advance of future regulations, to ensure that retrofit and new builds achieve a net zero carbon over their whole life cycle. This is why the RIBA created the 2030 Climate Challenge so that they could set, in their opinion, realistic targets for their member practices that sign up to take part.

The 2030 Climate Challenge states that low-density areas should be prioritised in regard to a net zero whole life carbon and that this could be achieved using on-site renewables. In contrast extra offsite renewable energy generation is likely needed for urban areas to achieve net zero whole life carbon cycle³².

Targets

Through the creation of the 2030 Challenge, the RIBA has established targets that tackle operational energy use, embodied carbon and water use reduction. These targets have been developed to consider the latest recommendations from the Green Construction Board (GCB) and has also gone through various consultations with other UK specialised bodies as well as the CCC.

To enable the RIBA Chartered Practices to act on the strong words set out in the Declaration of Climate Emergency, the RIBA set a list of reduction targets in the Climate Challenge, these targets are:

1. Reduce operational energy demand by at least 75%, before UK offsetting;

³¹ (Royal Institute of British Architects, 2019)

³² (Royal Institute of British Architects, 2019)

2. Reduce embodied carbon by at least 50-70%, before UK offsetting;
3. Reduce potable water use by at least 40%;
4. Achieve all core health and wellbeing targets³³;

It could be considered that the Climate Challenge document is currently not clear on how these targets will be measured; this is because the targets are only guidelines and are not legally binding; furthermore, taking part in the Challenge is optional and only aimed at RIBA practices. It is reasonable to suggest that it would be down to the architects to have documentary proof that they have met these targets, and in a worst case scenario it could be that an independent 3rd party monitors the project, which would add extra costs to a project.

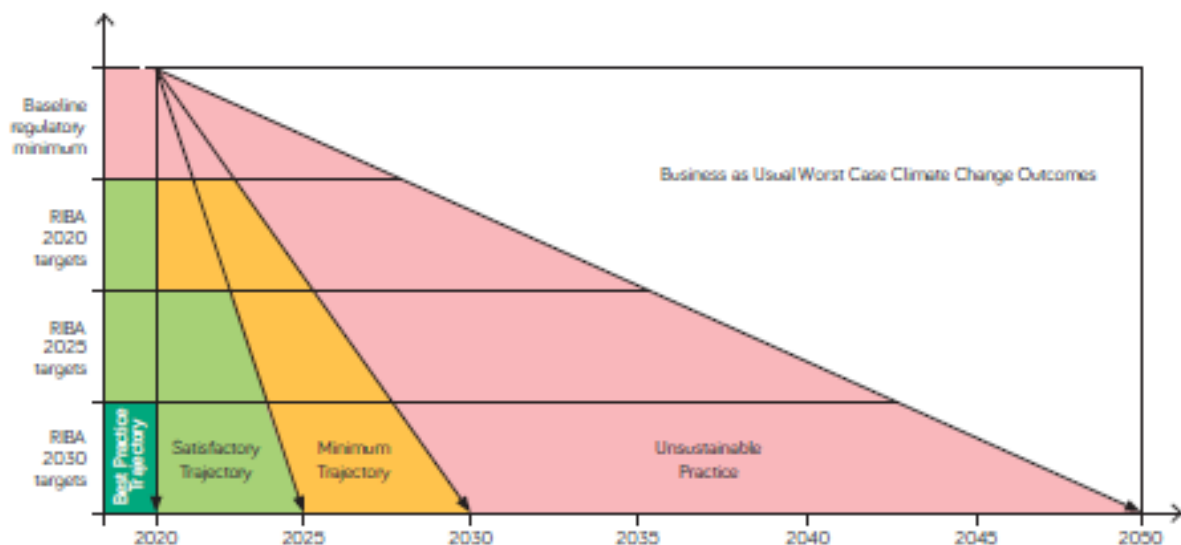
The RIBA state that these target reductions are possible despite appearing not having a clear understanding on how they plan on measuring whether a project achieves these targets. Furthermore, they plan on recommending them to the UK Government so that they can be added to future legislative documents.

The targets that have been set out in the 2030 Challenge are considered to be progressive, yet realistic to achieve by the RIBA; although, as previously stated, they have not, as yet, explained how they plan on measuring them. The RIBA selected these targets as they believe them to be a vital first step in ensuring that the construction industry can deliver the substantial emission reductions required by 2030. The RIBA believe by achieving the Challenge targets there is a more realistic prospect of accomplishing net zero CO₂ for the entire UK building stock by 2050. However, to make this possible and to have more of an impact on domestic projects, more architectural practices would be required to sign up, because as of 27th February 2020, so far only 90 of the 3,847 RIBA practices have signed up to the Climate Challenge³⁴. This is only 2.3% of the registered practices in the UK.

³³ (Royal Institute of British Architects, 2019)

³⁴ (Royal Institute of British Architects, 2020)

The targets set are based on both domestic and commercial buildings and will still require further fine-tuning by different sectors, building type, occupancy and geographical location³⁵. The RIBA have stated that they plan to develop additional metrics by collaborating with other UK expert bodies. However, given the urgency of the action required, it would be trivial to wait for the perfect benchmarks to be developed; with this in mind, the RIBA recommends that project teams try and aim for a percentage decrease of the current baselines and minimum regulatory standards³⁶.



Graph 1 RIBA 2030 Climate Challenge Trajectories
(Royal Institute of British Architects, 2019)

This Chapter examined the RIBA 2030 Climate Challenge, and the concept behind it, which is to promote sustainable design among architects. The 2030 Challenge was founded as a result of discussions between the RIBA and other professional bodies that believe architects, and the construction industry as a whole, play a key role in achieving the UK Governments target of decreasing greenhouse emissions to net zero by 2050³⁷.

To achieve this goal of net zero, the Challenge identified four key targets which were listed earlier in this Chapter. Currently there is no clear answer on how the RIBA plan on measuring and confirming whether a new project built under the Climate Challenge has met the targets.

³⁵ (Royal Institute of British Architects, 2019)

³⁶ (Royal Institute of British Architects, 2019)

³⁷ (Royal Institute of British Architects, 2019)

The architects who opt into taking part of the initiative must comply with the targets set out by it; however, these targets cannot be enforced legally, but by signing up to the Challenge, architectural practices are committing themselves to achieving them. The targets chosen for the Challenge were set as they were deemed to be progressive yet realistic to meet by the RIBA and are relevant for both domestic and commercial application³⁸. The Challenge has a critical role to play in the development of sustainable design in the UK, which has become more urgent since the Government set the task of reducing greenhouse gas emissions by 2050 to net zero, as it allows architects taking part in the 2030 Climate Challenge to work to deliverable targets.

As previously mentioned, this dissertation looks to explore how small architectural practices in Wales can be encouraged to adopt more sustainable design when dealing with domestic projects. With this in mind, the 2030 Climate Challenge seeks to promote sustainable design across all sectors of the construction industry, not just domestic; however, it is still optional; architects who wish to take part are required to sign up through the RIBA. As of the 27th February 2020, only 90 of the 3,847 RIBA practices have signed up to the Climate Challenge³⁹. This is only 2.3% of the registered practices in the UK. This figure shows that more still needs to be done to encourage practices to take part in the Challenge and to promote sustainable design.

The following Chapter looks at two different methods of sustainable design, passive and active, and identifies their principles and what makes them different.

³⁸ (Royal Institute of British Architects, 2019)

³⁹ (Royal Institute of British Architects, 2020)

Chapter 2 Passive and Active Sustainable Design

Chapter two examines two types of sustainable design approaches: passive design and active design. By identifying the key principles of these two approaches, it can be understood that there is a clear distinction between the two; firstly although both use natural resources in order to light, heat, cool and ventilate a building, they use them in different ways. For example, a passive design will use openable windows that will allow air to escape out of the building. Whereas, an active design will collect the electrical energy from photovoltaic panels to power a mechanical system that can cool the building and even extract the heat from this warm air and utilise it by using it to heat water for the building.

The use of both approaches in conjunction with each other will help a building reduce its CO₂ emission by curbing its reliance on non-renewable resources. However, they do not completely negate the need for gas and electric for heating and lighting etc. By educating clients on energy suppliers that provide electricity generated by renewable sources will further help to reduce CO₂ emissions.

Passive Sustainable Design Principles

Passive design principles aim at minimising the energy demand of a building. Proper consideration of the local climate and environmental elements, building layout, and material properties make the energy demand reduction possible⁴⁰.

For the purpose of this dissertation, passive design is regarded as a response to local climate and site conditions, and a way in which a building is designed to 'minimise' energy use whilst ensuring users comfort. It manages this by utilising free renewable sources of energy, like the Sun and wind, to provide heating, cooling, lighting and ventilation to the building. Capitalising on these free natural sources, reduces the need for mechanical heating and cooling. It is said that using a passive design strategy can also help improve internal air quality and reduce temperature fluctuations⁴¹. Passive design principles can be use on both new builds and extensions, however, due to the

⁴⁰ (Konstantinou & Prieto Hoces, 2018)

⁴¹ (Modscape, 2016)

nature of a project, some of the principles may not be able to be utilised on an extension or refurbishment.

Principles of passive sustainable design:

1. Building location and orientation onsite – it is important to consider the location and orientation of a building onsite in relation to seasonal changes, such as the Sun's path, as well as prevailing wind patterns. The right orientation of a building on a site can improve the energy efficiency, making it more comfortable to live in and less expensive to run.

2. Shading – when using passive design, the right amount of shading is important as direct sunlight can generate the same heat as a single bar radiator, (over each square metre of a surface) however, effective shading can block up to 90% of this heat.

There are various types of shading techniques, from fixed or adjustable shades to using trees and vegetation, depending on the building's position as well as climate and latitude. By shading a building and its outdoor spaces, internal summer temperatures can be reduced, improving comfort and save energy.

3. Thermal mass – can be used in domestic situations; however, it is not common. It is utilised by selecting materials that have the ability to absorb and store heat energy. High-density materials, such as concrete, bricks and tiles, are said to have high thermal mass properties. Whereas timber is a lightweight material and is considered to have low thermal mass properties. When thermal mass is used correctly it is able to help moderate internal temperatures and does so by averaging temperature extremes; this makes it greatly beneficial where there is a big difference between day and night outdoor temperatures⁴².

However, it is important to be aware that thermal mass is not an alternative for insulation, as thermal mass absorbs, stores and then re-releases heat, whereas insulation stops heat flowing into or out of the building.

⁴² (Hanania, et al., 2015)

4. Insulation – is used as a barrier to heat flow and is essentially for keeping a building warm in winter and cool in summer. A well-insulated and well-designed building will provide year-round comfort and cut cooling and heating bills by up to half.

Climatic conditions and overall wall thickness dictate the appropriate level and type of insulation; there are many different types of insulation, from more sustainable options, such as sheep's wool or recycled paper, to insulations made from plastics like polyisocyanurate (PIR) insulation. When selecting the appropriate insulation type, it needs to be established whether the insulation is principally needed to keep heat out or in (or both). Insulation needs to cater for seasonal as well as daily variations in temperature⁴³.

For a passive design to be effective, all the principles need to be considered holistically and work alongside each other⁴⁴. For example, using large windows which will help allow high levels of natural light would also result in excessive heat gain, particularly if they cast light on an area of thermal mass. Equally, opening windows to provide natural ventilation will also allow noise in. The use of passive design in the UK does not negate the need for additional active systems to be in place that will run off electric or gas to heat and light a domestic building etc.; however, by using these principles means that the building is not solely reliant on electricity or gas and, therefore, with the use of passive design with active systems in place can help lower the CO₂ emission produced.

Active Sustainable Design Principles

Active design principles are mechanical systems and devices that use or produce electricity to achieve a result, such as heating and cooling⁴⁵.

Active design differs from passive design as it primarily relies on mechanical systems that either uses, or is able to produce, electricity itself; the majority of existing buildings fall under this category. Putting this in context, if a passive design uses natural 'non

⁴³ (Green Match, 2019)

⁴⁴ (Modscape, 2016)

⁴⁵ (Jaffe, et al., 2020)

powered' systems to provide ventilation and heating, a building that uses active design achieves the same, but uses technologies, such as solar panels, heat recovery systems, or the use of renewable energy sources such as wind turbines.

Principles of active sustainable design:

1. Ventilation and Heat Recovery - mechanical ventilation with heat recovery (MVHR) systems helps to provide fresh filtered air into the building while being able to retain most of the energy that was already used to heat the building. These systems rely on electricity to power them, but this electricity could be generated via renewable resources or purchased from the grid in the form of a renewable electricity supplier.

An MVHR system is split into two elements, the first side is a heat exchanger; this sends warm fresh air to 'dry' rooms, such as bedrooms, living rooms, studies etc. via ductwork. While the other side of the system extracts the stale warm moist air from 'wet' rooms, such as bathrooms, kitchens, en-suites etc. through a second set of ductwork. When the warm stale air is sucked out of a 'wet' room it goes up through the ductwork to a heat exchanger. The heat is then removed from the warm stale air and passed, via the heat exchanger, to the cool fresh air on the other side which is coming in from the outside. The cold stale air is then expelled to the outside while warm fresh air is being brought back in to the 'dry' rooms⁴⁶.

2. Heating & Hot water

- a. Solar thermal - Solar water heating utilises the Sun's energy to work alongside a conventional water heater. Solar water heaters can be used in a domestic situation. To use solar water heating, typically 3 - 4m² of southeast to southwest facing roof, receiving direct sunlight for the main part of the day, is required for a domestic system to be effective⁴⁷.
- b. Heat Pumps – Heat pumps are very common in everyday life, fridges and air conditioners are two examples of where they are used. Likewise,

⁴⁶ (Eco-home-essentials, 2020)

⁴⁷ (Energy Saving Trust, 2020)

ground source heat pumps (GSHP) use the same principles but transfers heat from the ground into a building to provide space heating. It can also be used to pre-heat domestic hot water and work together with a conventional water heater.

GSHP uses lengths of pipe which are buried in the ground and installed either vertically in a borehole or a horizontally in a trench depending on space and ground conditions. The pipe is typically a closed circuit and is filled with a mixture of water and antifreeze. This mixture is pumped round the pipe where it can absorb heat from the ground. For every unit of electricity used to pump the heat around the circuit, 3 to 4 units of heat is produced⁴⁸.

As well as GSHP, air source heat pumps (ASHP) and water source heat pumps (WSHP) are also available. A heat pump can also transfer the heat to a hot water tank via an evaporator, a compressor and a condenser. The hot water tank can then feed the heating distribution system^{49, 50}.

Similarly, to mechanical ventilation and heat recovery systems, all heat pumps rely on electricity to power them; however, this electricity could be generated via renewable resources or bought from the grid from a renewable energy supplier. These systems are best used in conjunction with another system, such as a hot water boiler, as an active system such as solar thermal can preheat water before it gets to the boiler meaning that the boiler has less work to do; this helps reduce the amount of gas or electricity used to the heat water fully. Furthermore, if heat pumps are used in conjunction with underfloor heating, for example, it can negate the need to heat water further as underfloor heating does not to require the water to be as hot as traditional heating systems⁵¹.

⁴⁸ (Ground source heat pump Association, 2020)

⁴⁹ (Centre for Sustainable Energy , 2013)

⁵⁰ (Ground source heat pump Association, 2020)

⁵¹ (Ground source heat pump Association, 2020)

3. Electricity generation

- a. Solar Electricity – Photovoltaics (PV's) use energy from the Sun to create electricity which can be stored or used to run appliances and lighting, any unused electricity can be sold back to the grid. PV's do not require direct sunlight and can generate electricity in daylight. PV systems are available in a variety of shapes and colours, ranging from grey 'solar tiles' that look like roof tiles, to panels and transparent cells that you can use on conservatories and glass to provide shading as well as generating electricity⁵².
- b. Wind Turbines - Small scale wind turbines use the wind's lift forces to turn aerodynamic blades which are connected to a rotor which is used to creates the electricity⁵³. Turbines can vary in size and power output, from a few hundred watts to 2 or 3 megawatts. There are two typical domestic systems; these are pole mounted and building mounted and they can generate between 1 to 6 kilowatts, depending on type, size and location⁵⁴. With this in mind, wind turbines are not as commonly used on domestic projects as they require open space that is not sheltered. In addition, wind turbines are very prominent, so would not currently be suited for use in city centres. However, there is nothing to say they cannot be used, and as technologies get better, turbines may become more widely used on domestic projects.

When using active sustainable design, these principles are key. It is also necessary to use water conservation fixtures and appliances, such as choosing energy efficient appliances and lighting, providing exhaust fans in bathrooms and the kitchen to supply these internal spaces with a source of outside air. Similarly, to passive design, all the principles need to be considered and utilised to achieve an effective active design.

⁵² (Centre for Alternative Technology, 2020)

⁵³ (Energy Saving Trust, 2020)

⁵⁴ (Energy Saving Trust, 2020)

Whilst researching passive and active design principles it was noted that there is a lack of education when it comes to buildability and affordability of sustainable design compared to standard construction^{55, 56}. It is reasonable to suggest that due to this fact a stigma has emerged that using these methods could be more expensive than that of a standard construction.

It can be concluded from this Chapter, putting these two methods in simple context, a passive designed building would exploit the use of natural 'non powered' 'non mechanical' systems to provide cooling, ventilation and heating; such as using south facing windows to encourage solar gain which can naturally heat a building by using this alongside thermal mass to store heat within the building fabric and then releasing it slowly throughout the day. However, thermal mass can also be used to help keep the building cooler in the summer months as it absorbs heat.

In contrast, a building that uses active design would achieve the same as using passive design, but does so by using mechanical and electrical systems to generate its own power, and also uses other mechanical systems to ventilate and heat itself, such as solar thermal panels, mechanical ventilation and heat recovery systems. To generate its own power, active design uses renewable energy sources, such as wind turbines and PV's⁵⁷.

More research is required into the cost benefits of using active design principles, such as heat pumps, heat recovery systems and photovoltaic panels, as there are not only costs associated with construction, but there will be ongoing maintenance costs involved^{58, 59}. These costs need to be calculated alongside the potential running costs of a project using these systems, and then compared to a project running costs when these systems have not been used. Furthermore, similar calculations also need to be done when using passive design principles.

The following Chapter (Legislation) examines the different forms of Government legislation that effects buildings; these come in the form as national, regional, and local documents.

⁵⁵ (Anon., 2017)

⁵⁶ (Bergman, 2012)

⁵⁷ (Jaffe, et al., 2020)

⁵⁸ (Bergman, 2012)

⁵⁹ (Dobson, et al., 2013)

Chapter 3 Legislation

Chapter three examines building legislations in Wales, as they play a key role in how buildings are designed which can impact negatively on the ability of architects to use sustainable design for domestic client. There are numerous different legislative documents that are a prerequisite when dealing with the design of a building, most of these documents need to be read in conjunction with one another.

First there is planning legislation which is set at national level in documents, such as the National Planning Policy Framework (NPPF), thereafter, there are the regional legislative documents like the Planning Policy Wales (PPW) and Technical Advice Notes (TAN), and finally, there are the local legislative documents such as Local Development Plans (LDP's). Alongside these, there are a number of other policies and documents that also require consideration such as building regulations which are nationally compulsory, however, some of the documents differ regionally, between England, Wales, Scotland and Ireland due to the dissolved powers given to the individual UK Countries. There are also other legislative documents such as the Wellbeing of Future Generation (Wales) Act 2015. (See appendix B1 & B2 for information on NPPF & LDP's).

Planning policies and other legislative documents play an active role in guiding development towards sustainable solutions; decision on developments also need to take local circumstances into account, and are still required to reflect the character, needs and opportunities of each area.

The purpose of the planning system is to contribute to the achievement of sustainable development. At a very high level, the objective of sustainable development can be summarised as meeting the needs of the present without compromising the ability of future generations to meet their own needs⁶⁰.

⁶⁰ (Ministry of Housing Communities & Local Government, 2019)

Planning Policy Wales (Edition 10)

PPW legislation was created by the Welsh Government to set out land use planning policies. The PPW's primary objective is to ensure that planning systems of Wales contribute towards delivering sustainable development; these policies look to support and improve social, economic, environmental, and cultural wellbeing of Wales. The PPW document co-insides with the requirements of the Planning (Wales) Act 2015, the Wellbeing of Future Generations (Wales) Act 2015, and many other crucial legislative documents.



*Figure 4 Planning Policy Wales Edition 10
Front Cover
(Welsh Governmet, 2018)*

The PPW was created to promote action at all levels of planning, in order to capitalise on its contribution to the wellbeing of Welsh communities. The PPW also looks to encourage a broader outlook on sustainability and problem solving, focusing on assimilating, and addressing various issues instead of the approach of them being disjointed, un-coordinated and isolated. The legislation provides the prospect of removing perceived problems in current tactics and looks to support innovated and creative ideas. The PPW also encourages learning from previous development outcomes in order to drive sustainable improvements in planning practice as this is important.

The PPW document is supplemented by a series of TANs, Welsh Government Circulars, and policy clarification letters, which together with PPW provide the National Planning Policy Framework for Wales⁶¹.

⁶¹ (Welsh Governmet, 2018)

Technical Advice Note Wales (TAN)

The TAN document provides detailed planning advice used by the Local Planning Authorities (LPA) when preparing development plans. There are currently 20 documents in total which are used in conjunction with the PPW. The first TAN document was published on the 30th November 1996⁶². Each TAN document has its own role within planning legislations. For the purpose of this dissertation, the following TAN documents were looked at:

TAN 6: Planning for sustainable rural communities, provides practical guidance in supporting the delivery of sustainable rural communities. The guidance provided refers to how the planning system can contribute to:

- Sustainable rural economies;
- Sustainable rural housing;
- Sustainable rural services; and
- Sustainable agriculture⁶³.



Figure 5 Technical Advice Note 8 - Planning for Renewable Energy Front Cover (Welsh Government, 2005)

TAN 8: Renewable energy, was created to provide technical advice to supplement the PPW on Renewable Energy policies contained in it. Local planning authorities in Wales take these documents into account when preparing local development plans. These documents will also be material to decisions given to individual planning applications, as well as appeals against those decisions. TAN 8 is also relevant to the authorisation of electricity generation schemes that the UK Government have implemented under section 36 of the Electricity Act 1989⁶⁴.

⁶² (Welsh Government, 2017)

⁶³ (Welsh Government, 2010)

⁶⁴ (Welsh Government, 2005)

TAN 12: Design, sets out to equip all those involved in the design process of a development with advice on how 'Promoting sustainability through good design' and 'Planning for sustainable building' may be facilitated through the planning system.

The document does not provide exhaustive text on good design, as it is to be read in conjunction with other TAN documents that may also cover design issues; however, these will be more relevant to specific topics or types of development.

The TAN 12 document also stipulates that design issues, as influenced through the planning system, should not duplicate the role of building regulations. It is a general rule that planning is typically responsible for the building relationship with the surrounding area and its external appearance, and that building regulations deal with the technical performance of a building's structure and services. However, initial designs of a building, even during the planning process, needs to consider the requirement for a building to meet building regulations. This means that when designing a building, it is fundamental that both planning and building regulations are considered from the outset, and do not get treated or developed in isolation⁶⁵.

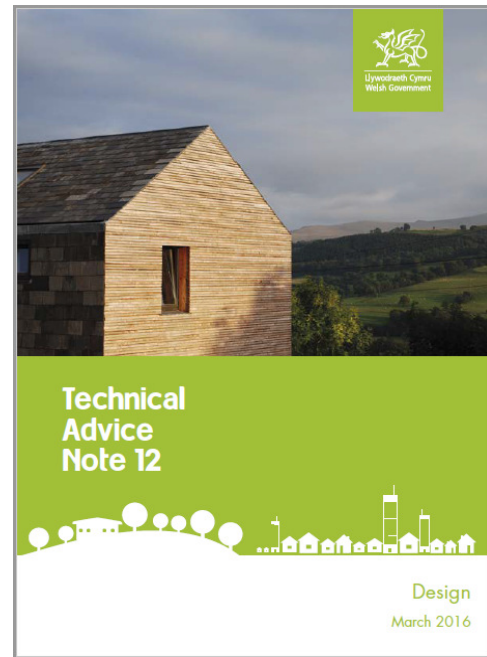


Figure 6 Technical Advice Note 12 -Design
Front Cover
(Welsh Government, 2016)

⁶⁵ (Welsh Government, 2016)



Figure 7 Technical Advice Note 15 - Development and Flood Risk Front Cover (Welsh Government, 2004)

TAN 15: Development and flood risk, explains that flooding of rivers and coastal waters is a natural process, and a natural phenomenon which is very difficult to predict and plays a key role in shaping the environment; However, due to climate change, it has become relatively more common for flooding to happen; this is only exacerbated by developing land in proximity to or on a natural flood plain, of which the consequences can be very significant. Flooding has a massive impact as it places lives at risk, causes considerable personal trauma and results in extensive damage to property; this often amounts to millions of Pounds⁶⁶.

With this in mind, TAN 15 seeks to provide technical guidance to supplement the policy set out in PPW in relation to development and flooding. The document advises on development and flood risk, as this relates to sustainability principles in section 2.2 of PPW. It provides a framework within which risks, arising from both river and coastal flooding, can be assessed and examines how additional run-off from a development, in any location, will impact the area. There are also a set of advice maps to accompany this TAN document which should be available from local planning offices⁶⁷.

Wellbeing of future Generation (Wales) Act 2015

The Well-being of Future Generations (Wales) Act 2015 was developed with the intent of improving the social, economic, environmental, and cultural well-being of Wales. The Act was created to help Wales become a vibrant and attractive place in which all would want to live now and, in the future⁶⁸.

The Act was created as a response to a number of challenges faced now, and in the future. These challenges include, climate change, poverty, health inequalities, jobs and growth. The Act states that to help tackle these challenges, people need to work

⁶⁶ (Welsh Government, 2004)

⁶⁷ (Welsh Government, 2004)

⁶⁸ (Sustainable Development Branch Welsh Government, 2015)

together and develop a more sustainable way of life in order to give current and future generations a good quality of life; and when developing areas, consideration needs to be given to the long-term impact of the decisions made⁶⁹.

Building regulations

Building regulations approval is different to planning permission as they set out the minimum standards for design, construction and alterations to virtually every building. Building regulations approval can be applied through either the Local Building Control department of the Local Authority, or an independent Approved Building Inspector. The regulations are developed by the UK Government and approved by Parliament; however, some regulations differ regionally, due to dissolved powers given to the Welsh Government, Scottish Parliament and the Irish Government. There are approximately 20 building regulation documents that a design must be complied with, and cover a range of different topics, such as Structure and Fire Safety to Security and Physical infrastructure for high speed electronic communications networks⁷⁰.

For the purpose of this dissertation, the following Part L approved document was deemed to be what would affect sustainable design the most. There are four documents that make up Part L, covering different types of developments, such as new builds and extensions/conversions to existing buildings.

These documents are:

- L1A Conservation of fuel and power in new dwellings;
- L1B Conservation of fuel and power in existing dwellings;
- L2A Conservation of fuel and power in new buildings, other than dwellings;
- L2B Conservation of fuel and power in existing buildings, other than dwellings.

Part L sets out the minimum standards on insulation regulations, boiler productivity, lighting, and storage techniques for hot water. It also provides further information covering things like the standards for Carbon Index ratings, solar emissions, heating

⁶⁹ (Sustainable Development Branch Welsh Government, 2015)

⁷⁰ (Planning Portal, 2020)

and ventilation systems, space heating controls and air conditioning systems, amongst other fuel and power systems⁷¹.

Chapter three focused on the different types of legislation that must be consider when designing a new development, whether that be domestic or commercial.

From the research gathered on planning legislation, it was noted that the planning systems look to encourage sustainable design; however, does not promote it enough. Furthermore, these documents also do not allow for an individual's interpretation of the policies contained in the documents; not only that, there have been instances where policies can overlap and conflict with one another. The LPA may also interpret the policies differently. Due to the complexity of planning legislation in general, and when it comes to passive design, it is conceivable that small architectural practices, especially those in Wales, consciously or sub consciously avoid embedding passive design principles into their projects.

There are also other documents such as the Wellbeing of future Generation (Wales) Act 2015, which look to encourage sustainable design, however, does not enforce it.

Building regulations do not go far enough in encouraging sustainable design as they only set the minimum standard to which buildings are required to meet. This is especially true regarding Part L, which focuses on the thermal performance of a building, along with how it is heated and cooled, which are key elements of creating a sustainable development^{72, 73}.

The following Chapter (Methodology), discusses the data collection methods used within this dissertation, which is to be based on four case studies selected. It also sets out how the data will be collated and will examine a number of variables in which the case studies are to be compared. The data collected will be used to examine the use of a sustainable design approach on domestic jobs, compared to a standard building design.

⁷¹ (Planning Portal, 2020)

⁷² (Welsh Government, 2014)

⁷³ (Welsh Government, 2014)

Chapter 4 Methodology

Chapter four explores the methodology of the chosen approach of data collection through case studies; the data collected will be used to examine the use of a sustainable design approach on a domestic job, compared to a standard building design. The data will be collected from secondary sources and used to fill out a data matrix in the following Chapter. The information also required to fill out the data matrix will be set out in this Chapter; the type of data collected will fall under variables, such as cost, size and CO₂ emissions etc.

Methodology

Chapters four and five of this dissertation has adopted a case study approach to collect and analyse data. The data collected will be used in the following Chapter to complete a data matrix table, which is set out below. Data matrices have been selected to help compare key components of information for each selected case study⁷⁴. The information collected and used will be from secondary sources, such as reports, publications, journal articles and conference papers.

Data Matrix Table

Variables	Case Study 1	Case Study 2
Job Type		
Year Completed		
Size (m²)		
Total Cost		
Design		
CO₂ Emissions (kg/m²/years)		

Table 1 Data Matrix Template 1

⁷⁴ (Nadin & Cassell, 2004)

Variables	Case Study 3	Case Study 4
Job Type		
Year Completed		
Size (m²)		
Total Cost		
Design		
CO₂ Emissions (kg/m²/years)		

Table 2 Data Matrix Template 2

Variables

Variable 1: Job Type

Variable one identifies the job type, for example, a new build or an extension to an existing building. Each case study will fall into one of these categories; this will allow for a comparison of each to explore the use of sustainable design in both situations compared to a standard design.

Variable 2: Year Completed

Variable two states the year in which the project was completed; this will assist when it comes to comparing costs. This variable will help explore potential change in construction method over a period of years.

Variable 3: Size (m²)

Variable three calculates the size of the selected studies by using the total floor area. This variable will be used in conjunction with the total cost variable,² to work out the cost pre m² of each study; this will help with comparing the cost of the selected case studies. Each case study selected will be of a similar size.

Variable 4: Cost

Variable four compares the cost of each project using this alongside the floor area variable, an estimate cost per m² can be calculated. These will only be estimates because a breakdown cost for each study may not be available, which means an accurate illustration of the expenditure may not be possible. Using the cost per m² will identify how costs may vary between new builds to extensions.

Variable 5: Design

For variable five, the construction of each building will be examined to identify whether a sustainable approach was adopted in the design and if so, which method was used. To identify what approach was used, the principles acknowledged and discussed in Chapter 3 will be utilised and checked against each selected case study.

Variable 6: CO₂ Emissions

Variable six looks at the CO₂ emissions for a year, per property; this variable will then be used to explore the impact of sustainable design on the yearly CO₂ emissions for a sustainable domestic building compared to the CO₂ emission of a standard building design. By doing this for both domestic new builds and extensions, and using the cost per m² to work out for the previous variables, it may be possible to work out the cost difference of adopting a sustainable approach to that of a standard building design.

Chapter four has discussed the choice of data collection; that is, case studies based upon secondary sources. By the use of a data matrix the author has set out the variables in which these projects were assessed and compared with each other. The variables chosen to do this are: building use, job type, year completed, total cost, floor area m², method of sustainability, CO₂ emissions.

These case studies and variables will be used in the following Chapter (Findings), to help explore what makes a building sustainable and of a standard design approach; it will also compare the cost of building a sustainable building with a standard building by working out the difference in cost per m², and will finally analyse how the CO₂ emissions for a year vary from building sustainably to non-sustainably.

Chapter 5 Case Study Comparisons

Chapter five identifies the selected case studies, and uses the information obtained to fill out the data matrix set out in the previous Chapter. With the completion of the data matrix, this Chapter will expand on each of the case studies in order to provide more context for the data.

The case studies for analysis were selected for the following reasons:

All the projects are domestic in nature, however, two are new builds and the other two are extensions. Each project was built within the last decade, of similar size, were funded privately and were of similar build costs.

Case Study 1: New Build (Elfort Road)

Case study one is a two-bedroom new build house, located on Elfort Road, Islington, London; the project was completed in January 2014. Studio 54 Architecture did the initial design for the scheme, Michael Barclay Partnership (MBP) were the Structural Engineers for the project, and the main contractor was Fuller Builders⁷⁵.



Figure 8 Image of Case Study 1 Elfort Road
(Architectural Journal , 2020)

The site on which the house sits is a brownfield site and was previously being used for car parking. The site is constrained between the flank walls of two terraces, one Victorian and the other post-war; there were also neighboring houses facing into the site⁷⁶.

Elfort Road is primarily set over a single storey with a small basement area for storage to maximise the usable space. The floor plan has an open plan kitchen, dining, and living space which face west towards the street and east towards the garden. There is a closed off access stairs to the basement within the living space; a corridor off the kitchen dining area, that has been naturally lit with a series of roof lights, leads to a

⁷⁵ (Architectural Journal , 2020)

⁷⁶ (Architectural Journal , 2020)

bathroom and two double bedrooms, one of which is the master bedroom which has its own en-suite. The building is primarily heated by under floor heating, there is also a wood burning stove which acts as a focal point for the living area⁷⁷.

The project was deliberately robustly crafted; with the walls being handmade brick by Petersen; doors and windows are bespoke cedar with cedar cladding internally and externally, the floors are tiled throughout. The timber joists over main areas have been left exposed and painted grey; the ceilings to circulation and service areas were left smooth and painted white. The roof is a bio-diverse green roof planted with wildflowers⁷⁸.



Figure 9 Image of Case Study 2 Fernaig Cottage
(Architectural Journal, 2020)

Case Study 2: Extension (Fernaig Cottage)

Case study two is a refurbishment to a dilapidated traditional Scottish Longhouse, in Achmore, in the Scottish Highlands and is the only building on its side of the Glen; the project was completed in February 2016, and was designed by Scampton and Barnett Architects who are also the client. There were two different Structural Engineers on the job: Expedition Engineering were involved in the original concept, and the IPM Associates carried out the detailing for the project. Finally, the main contractor were Adam McDonald Building and Joinery⁷⁹.

Fernaig Cottage involved the construction of a single storey extension. The extension creates a new open plan kitchen, dining, and living space. The existing cottage was refurbished to create three bedrooms and a bathroom. The new extension was designed to a minimum footprint to ensure a commonality of scale between each part of the cottage to preserve green space on site. Stone that was removed from the

⁷⁷ (Architectural Journal , 2020)

⁷⁸ (Architectural Journal , 2020)

⁷⁹ (Architectural Journal, 2020)

existing cottage was re-used, combined with new red roofs to unite the two structures sympathetically⁸⁰.

The new build offers an open, lofty single volume, which provides a scale that although is different from the older part or the cottage, compliments it. The extension has been highly insulated and is punctuated by precisely placed openings to the north, south, east, and west to provide varying patterns of light throughout both day and season⁸¹.

The building was designed to be highly sustainable; by ensuring the new extension is well insulated and allowing the old section of the cottage to remain breathable. It also benefits from the use of an air source heat pump, and an MVHR system. In addition, the re-use of stone and minimum built volume means material use where limited⁸².

Case study 3 New Build (Adolphus Road)

Case study three is also a two-bedroom new build house, and is located on Adolphus Road, Finsbury Park, London, and was completed in May 2017. The Architects involved in the project were GPAD London Ltd. and the Structural Engineers were GDC Partnership Ltd⁸³.

The site on which the house sits was constrained to a plot of land that was only six by seven metres and housed a small garage in the south east corner. The plot is also located at the end of a Victorian terrace and is overlooked by neighboring houses⁸⁴.

Adolphus Road is set over three stories: comprising of a basement, ground floor and first floor. The ground floor is primarily an open plan living space containing the kitchen,



Figure 10 Image of Case Study 3 Adolphus Road (Architectural Journal, 2020)

⁸⁰ (Architectural Journal, 2020)

⁸¹ (Architectural Journal, 2020)

⁸² (Architectural Journal, 2020)

⁸³ (Architectural Journal, 2020)

⁸⁴ (Architectural Journal, 2020)

dining area, and lounge. The first floor contains the master bedroom which has its own walk in wardrobe and en-suite bathroom. The basement contains the second bedroom with a study, a bathroom, a utility area, storeroom, and a plant room⁸⁵.

The overall design of the house is carefully considered. The innovative layout and clever layering of spaces ensure the interior areas feel airy and spacious; doors and windows were used to flood the rooms with natural light where possible⁸⁶.



Figure 11 Image of Case Study 3 The Lodge - Bedford Park Mansions
(Architectural Journal, 2020)

Case study 4 Extension (The Lodge - Bedford Park Mansions)

Case study four is an extension and refurbishment work to a Porter's Lodge built in 1900, in The Orchard, London and was completed in October 2010. The Architects involved in the project were Sidell Gibson Architects and the Structural Engineers were Hockey & Dawson⁸⁷.

The old Porter's Lodge is attached to the southern section of Bedford Park Mansion. The block style mansion to which the porter's lodge is connected to, was the first to be built in this area and was completed in the 1900s. The primary constraints on this job were of a conservation nature; this is because although the lodge and mansion are not listed, the site itself is surrounded by Grade II listed houses⁸⁸.

The Lodge is based over two floors; a simple steel spiral staircase has been used to connect the ground and first floors which allow for maximum natural light to penetrate from above. The ground floor plan contains a small entrance lobby to the building, and then the rest of the floor is an open plan living space made up of kitchen, dining and

⁸⁵ (Architectural Journal, 2020)

⁸⁶ (Architectural Journal, 2020)

⁸⁷ (Architectural Journal, 2020)

⁸⁸ (Architectural Journal, 2020)

lounge areas. The first floor is divided into two bedrooms, one with an en-suite bathroom, and finally a wet room⁸⁹.

The block is built in the Queen Anne style, popular in the late 19th Century, featuring red brick, terra cotta reliefs, Dutch gables and crenulated parapets⁹⁰.

Data Matrix Tables

Variables	Case Study 1 Elfort Road	Case Study 2 Fernaig Cottage
Job Type	New Build	Extension and Refurbishment Works
Year Completed	Jan 2014	Feb 2016
Size (m²)	84m ²	85m ²
Total Cost	Total cost £250,000 Estimate cost £2,976.19per m ²	Total Cost £205,000 Estimate cost £2,411.76per m ²
Design	Passive Design	Active Design and built using local materials
CO₂ Emissions (kg/m²/years)	17.4kg/m ² /years	23kg/m ² /years

Table 3 Completed Data Matrix 1

Variables	Case Study 3 Adolphus Road	Case Study 4 The Lodge
Job Type	New Build	Extension and Refurbishment Works
Year Completed	May 2017	Oct 2010
Size (m²)	77m ²	80 m ²
Total Cost	Total cost £240,000 Estimate cost £3116.88per m ²	Total cost £170,000 Estimate cost £2125.00per m ²
Design	Standard building design	Standard building design
CO₂ Emissions (kg/m²/years)	1723.69kg/m ² /years	1700kg/m ² /years

Table 4 Completed Data Matrix 2

⁸⁹ (Architectural Journal, 2020)

⁹⁰ (Architectural Journal, 2020)

Findings

Job Type

Case study one, Elfort Road and case study three, Adolphus House, are both new build houses. Case study two, Fernaig Cottage, and case study four, The Lodge, are both extensions, with refurbishments also being carried out on the other areas of the properties.

Year Completed

The four selected case studies were all built within the last decade; the most recent is case study three, Adolphus House, which was completed in May 2017. The next is case study two, Fernaig Cottage, being completed February 2016; followed by case study one, Elfort Road, which was completed in January 2014, and finally the oldest being case study four, The Lodge, which was completed in October 2010.

Size (m²)

All four case studies are of similar size and are less than 90m². Case study one, Elfort Road, is 84m², case study two, Fernaig Cottage, is 85m², case study three, Adolphus Road, is the smallest of all the case studies at only 77m², and finally case study four, The Lodge, is 80m². These figures will be used in conjunction with the total project cost to work out an estimate cost per m². The figures can also be used in conjunction with the CO₂ emissions per m² to calculate the total amount of CO₂ emissions each case study produces a year.

Cost

The cost for each case study varied due to a number of different factors; the biggest factor being the year built. This is because cost of construction goes up each year; the prices of each case study does not take into account price inflation.

Some of the other factors that affect the cost are where they were built, as regional cost varies; for example, the cost of building in London is more expensive than building in Cardiff⁹¹. There is also the type of project, as prices can be potentially higher on an

⁹¹ (European Construcion Costs, 2020)

extension compared to a new build as an existing building is being dealt with. A further consideration is whether the project was a standard construction or of a higher standard to be more sustainable.

Design

Out of the four case studies selected, two adopted a sustainable design approach and the other two were of a standard approach. Using the principles discussed in Chapter two, and background information gathered on the case studies, it was concluded that case study one, Elfort Road, adopted a passive design approach, whereas case study two, Fernaig Cottage, used an active design approach, however, Fernaig Cottage did utilise local materials in the construction. Case studies three, Adolphus Road, and four, The Lodge, were built using standard design and construction.

CO₂ Emissions

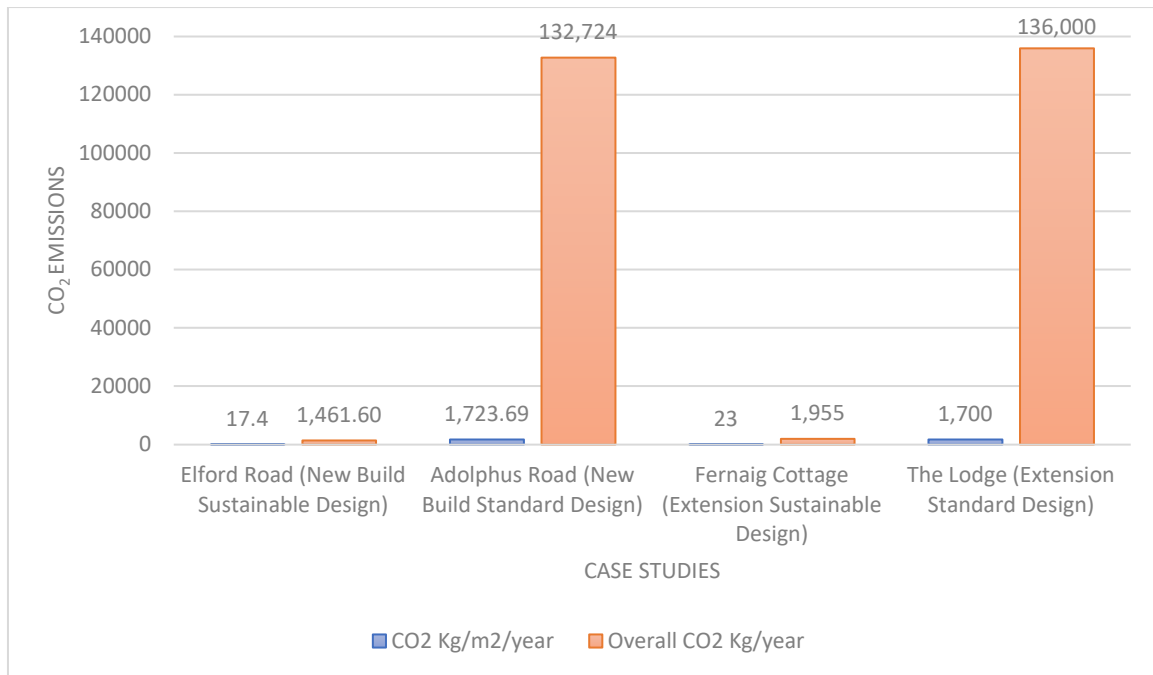
One of the key variables of the case studies are the yearly CO₂ emissions which are measure by Kg/m²/year and illustrates how much of a positive impact designing a higher standard can impact on a dwelling's contribution to climate change.

Case study one, Elford Road, which is a new build and was designed with a sustainable approach is estimated to release 17.4Kg/m²/year of CO₂, multiply this by the properties size 84m² its yearly emission 1,461.6Kg/year of CO₂.

Case study two, Fernaig Cottage, which is an extension and refurbishment of an existing building also adopted a sustainable approach and is estimated to release 23Kg/m²/year of CO₂, due to the property size this equates to 1,955Kg/year of CO₂.

Case study three, Adolphus Road, which is also a new build but was design to a standard approach and is estimated to release 1,723.69Kg/m²/year of CO₂, due to the property size this equates to 132,724.13Kg/year of CO₂.

Finally, case study four, The Lodge, which is an extension and refurbishment of an existing building also used a standard design approach, and is estimated to release 1,700Kg/m²/year of CO₂, due to the property size this equates to 136,000Kg/year of CO₂.



Graph 2 CO₂ overall building and m² CO₂ emissions for each case study per year

Chapter five identified and gave a brief summary of each of the case studies used to complete the data matrices. Following the completion of the table, the Chapter also expanded on the variables. Using the information collected in this Chapter, the following Chapter will look to analyse and compare the data in order to discuss the benefits of using a sustainable design to a standard design.

Chapter 6 Analysis

As previously mentioned, the aim of this dissertation is to investigate and analyse how small architectural practices in Wales can be encouraged to adopt more sustainable design, when dealing with domestic projects. Furthermore, this dissertation will look at the types of design approach available, and what is currently being done to promote sustainable design in general, by researching UK legislation and other methods of promotion.

Chapter six analyses the findings from research into two different sustainable design approaches, known as passive and active design principles. Thereafter, the case studies used in the previous Chapters will be examined. This Chapter will use the case study findings to examine the use of sustainable design principles on a new build house, and an extension with refurbishment work to an existing house and compare them to similar projects which are of standard design. The analysis will be used to examine the impact on the yearly CO₂ emissions for each situation.

The case study data analysed for this report is in the form of a cross-sectional time horizon, as the data collected was from a pre-set moment in time.

Design

For the purpose of this dissertation, sustainable design refers to active and passive design principles. Referring to Chapter two, and the principles that were identified in relation to the two selected methods, it can be seen that the principles behind these sustainable design approaches are simple, such as utilising natural resources like wind and solar energy etc. to either heat and cool a building or to produce energy to power mechanical systems to do this.

However, when it comes to the use of passive design principles in the UK, it does not negate the need for additional active systems to be in place that will run off electric or gas to heat and light etc. a domestic building. Using the principles associated with passive design means that a building does not solely rely on electricity or gas and, therefore, the use of passive design alongside active systems which generate their own power, or can be powered by electricity purchased from the grid that is sourced

from suppliers that generate electricity through renewable sources will in effect, reduce a buildings CO2 emissions.

Case study analysis

Case study one, Elfort Road, has adopted passive design principles. This can be seen by the creative use of the site and layout of the internal spaces which allowed for the best penetration of natural light into the building. It achieves this by utilising large windows in the bedrooms that faced south east

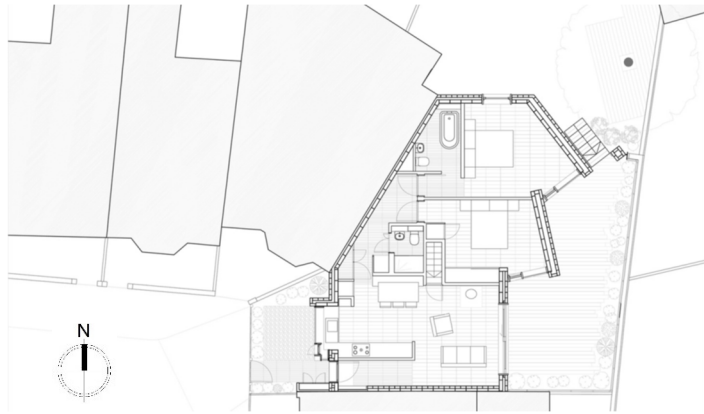


*Figure 13 Image of Elfort Road Floor Plan
(Architectural Journal , 2020)*

and the sliding door to the living area that faced east. Roof lights over the inner corridor between the kitchen, dining area, and bedrooms allowed this area to be flooded with natural light also.

The large windows and sliding door also provide the building with the means to be naturally ventilated, allowing the internal spaces to be cooled naturally which are also considered passive design principles. Elfort Road was also designed to be well insulated which helps keep the internal spaces warm in the winter months. Applying these simple passive design features, in this case to a new build, not only provided the project with a bespoke look, but also allowed the building to meet most of the passive design principles, which ultimately lowered its contribution of CO₂ emissions for a year.



Figure 14 Image of Fernaig Cottage Floor Plan (Architectural Journal, 2020)

The design behind case study two, Fernaig Cottage, utilised both passive and active design principles. The new extension was designed to be well insulated and had large windows to the north, east, south and west, allowing natural light to penetrate the centre of the building, which are passive design principles. The building also benefits from the use of an ASHP, and an MVHR system to heat and cool the internal spaces, which are active design principles.

Finally, the material used in the construction of the extension were sourced locally and in the case of the stonework, it was reclaimed and re-used from the existing cottage. Again, by applying a little more consideration and some simple design features, in addition to utilising mechanical systems, in this case, to an extension and refurbishment of an existing building, the project was able to lower the buildings overall contribution of CO₂ emissions for a year.

In the case of case study three, Adolphus Road, and case study four, The Lodge, no sustainable designs were adopted; this is dramatically evidenced by their CO₂ emissions.

CO₂ Emissions

One of the most valuable findings from the case studies were the yearly CO₂ emissions for each project. These findings only help to prove that sustainable design really can make a difference in domestic situation when utilised.

By analysing the findings of the CO₂ emissions, of both case study one which utilised a sustainable design approach, and case study three which was a standard design approach, both of which were new build projects, revealed that there is a 98% reduction of CO₂ emissions a year from using a sustainable design approach compared to the standard design.

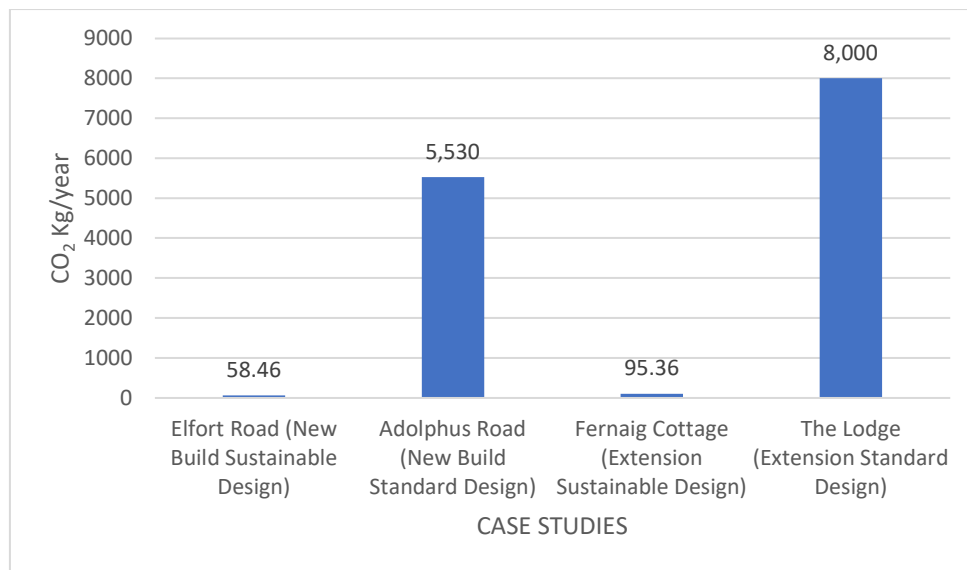
Doing the same with the CO₂ emissions from case study two which utilised a sustainable approach, and case study four which was a standard design approach, and are both extensions and refurbishment works to existing building, again revealed a 98% reduction of CO₂ emissions a year from adopting a sustainable design approach.

To help compare the CO₂ emission in cost, a calculation was used to work out how much CO₂ was released a year for every £10,000 spent on the construction of the project. The results were as follows (see appendix for full calculations):

- Case study one, Elford Road, (sustainable new build project) 58.46Kg/year of CO₂ for every £10,000 spent on construction;
- Case study two, Fernaig Cottage, (sustainable extension and refurbishment work) 95.36Kg/year of CO₂ for every £10,000 spent on construction;
- Case study three, Adolphus Road, (standard new build project) 5,530.17Kg/year of CO₂ for every £10,000 spent on construction;
- Case study four, The Lodge, (standard extension and refurbishment work) 8,000Kg/year of CO₂ for every £10,000 spent on construction.

Comparing the both new builds, case studies one and three, it can be seen that there is a saving of 5,471.71Kg/year of CO₂ for every £10,000 spent on construction when using a sustainable design approach to that of a standard design which is an incredible difference.

Again, if both extensions are compared, case studies two and four, a saving of 7,904.64Kg/year of CO₂ for every £10,000 spent on construction is achieved from using a sustainable design instead of a standard design.



Graph 3 CO₂ per Kg/year for every £10,000 spent on build

If small architectural practices in Wales are conversant with these CO₂ emission savings per m², it is reasonable to suggest that they will be in a better position to not only negate the stigma of which has attached itself to sustainable design and small domestic jobs regarding its affordability and buildability, but explain the cost benefits of using both passive and active design principles to their clients. However, further promotion and education is still needed via RIBA and other professional bodies to the cost benefits of using passive and active principles.

RIBA Promotion & Welsh Legislation

When considering what is currently being done to encourage small architectural practices in Wales to adopt more sustainable design for domestic projects, data collected in the Introduction on architectural practices in the UK and data collected in Chapter one on the RIBA 2030 Climate Challenge were analysed. The data collected shows there are 7,515 practices in the UK⁹² and only 3,847 of them are RIBA registered⁹³. From this it can be concluded that nearly 48% of the practices in the UK cannot take part in the RIBA 2030 Climate Challenge as the Challenge is only available to RIBA members. Furthermore, as stated in Chapter one, as of the 27th February

⁹² (Construct UK Ltd, 2020)

⁹³ (Royal Institute of British Architects, 2020)

2020, only 90 chartered practices had signed up to the Challenge⁹⁴; this is only 2.3% of the RIBA registered architectural practices in the UK, and only 1.2% of the architectural practices in the UK as a whole. With this in mind, more needs to be done, not only to promote sustainable design to practice that are part of the RIBA, but to all practices across UK.

Planning legislation plays a key role in architects using sustainable design for domestic projects. It can be seen that the planning systems in Wales looks to encourage sustainable design, but due to the complexity of some of the legislation it can lead to misunderstanding of policies⁹⁵. This is because the documents do not allow for an individual's interpretation of the policies contained in the documents; not only that, but how policies interrelate with one another, as there are instances where policies can overlap and conflict with one another. The LPA may also interpret the policies differently to that of an architects' practice.

Furthermore, due to the complexity of planning legislation in general, and when it comes to passive and active design, it is conceivable that small architectural practices, especially those in Wales, consciously or sub consciously avoid embedding these design principles into their projects.

There are also other documents, such as the Wellbeing of future Generation (Wales) Act 2015, which look to encourage sustainable design, However, this document is not legally binding so has no way of being enforced.

There are also building regulations which do not go far enough in encouraging sustainable design; this is because they only set the minimum standard to which building are required to meet. This is especially true in regards to Part L, which focuses on the thermal performance of a building, along with how it is heated and cooled which are key elements of creating a sustainable building^{96 97}.

From the analysis carried out in this Chapter on the findings from the previous Chapter, it can be concluded that the reduction of CO₂ emissions when adopting a sustainable

⁹⁴ (Royal Institute of British Architects, 2020)

⁹⁵ (Geyer & Cairney, 2015)

⁹⁶ (Welsh Government, 2014)

⁹⁷ (Welsh Government, 2014)

design is substantial. In the case of the sustainable case studies selected, these reductions were achieved by very simple consideration, such as the use of a well-insulated external shell, window/door sizes, floor layouts and use of additional mechanical systems in case study two. By comparing the CO₂ emissions released in a year for every £10,000 spent on a project the affordability of sustainable design seems more realistic when you compared this with standard design.

Chapter 7 Conclusion

Chapter seven draws together a conclusion from the research undertaken in this dissertation. It will also look to make recommendations on how small architectural practices in Wales can be encouraged to adopt more sustainable design. This Chapter will also look to identify future areas of research that can be carried out to help support the use of sustainable design on small domestic projects and that of large-scale residential developments.

Conclusion

This dissertation set out to explore how small architectural practices in Wales can be encouraged to adopt more sustainable design for domestic projects. This is because climate change is becoming more and more apparent, with dramatic changes to weather patterns around the world. With this in mind, the UK construction industry is attempting to do its part to reduce its CO₂ emissions, and adopt more sustainable design and construction methods.

In order to fully understand the meaning of sustainable design, the two most commonly used design principles, passive and active, were discussed.

Using sustainable design is becoming more and more common on large scale commercial and educational projects. However, the use of sustainable design, by small architectural practices, on small domestic projects, such as individual houses, extensions and loft conversions, which contributes to 49% of the overall types of projects in the UK, is being left behind.

Case Studies

The case study data reveals a difference in the CO₂ emission per year from using a sustainable design solution when compared to a standard design solution. This was expected to be the case, however, the impact on the CO₂ emissions that were noted were far more dramatic than was anticipated.

The design solutions utilised in the case studies were simple considerations embedded into the projects that help them to adopt a sustainable design, such as insulation, positioning of window and door openings, and floor layouts.

It can be concluded from the case studies, that with a little more consideration, projects could achieve a sustainable design

From research conducted it has been concluded that the main barriers to affecting small architecture practices in Wales from adopting more sustainable design when dealing with domestic projects are:

- Planning legislation does encourage sustainable design; however, it does not promote it.
- Legislative policies overlap and conflict with each other.
- LPA may also interpret the policies differently to each other.
- Architects can misinterpret policies contained in legislative documents. Furthermore, due to the complexity of planning legislation in general, and when it comes to passive and active design, it is conceivable that small architectural practices, especially those in Wales, consciously or sub consciously avoid embedding these design principles into their projects.
- Documents, such as the Wellbeing of future Generation (Wales) Act 2015, looks to encourage sustainable design, however, their recommendations are not enforceable
- Building regulations do not go far enough in encouraging sustainable design as each document only sets the minimum standard to which buildings are required to meet. This is especially true regarding Part L which focuses on the thermal performance of a building, along with how it is heated and cooled which are key elements of creating a sustainable development.
- Although there is currently legislation and measures in place to promote sustainable design, these do not go far enough.
- The RIBA do not go far enough to encourage their members to join the 2030 Climate Challenge
- A lack of education for architects has resulted in their clients being uninformed, as well as misinformed about the sustainable design approaches available,

such as passive and active, which further results in clients not even considering these design approaches as options.

- There is a stigma which has attached itself to sustainable design and small domestic jobs regarding its affordability and buildability

Recommendations

- Planning legislation should actively promote the use of sustainable design practices. If planning legislation actively promotes the use of sustainable design, small architect practices will be encouraged more to use it for domestic projects.
- Legislative policies should be amended to avoid them overlapping and conflicting with each other; in doing so, small architectural practices will be less confused by the legislations leading to better understanding of what can and cannot be done.
- LPAs must have a consistent and unified way of interpreting policies. This will make it easier for small architectural practices, who work across several LPAs to effectively use sustainable design with less chance of objections from LPAs.
- Policies within legislative documents should be simplified and clarified to avoid misinterpretation by architects
- Recommendations from documents, such as the Wellbeing of future Generation (Wales) Act 2015, which look to encourage sustainable design, should be embedded in enforceable legislation
- Building regulations, especially part L, which set out the minimum standard of which buildings are required to meet should be set at a higher standard, to include sustainable design methods
- Currently legislation and measure that are in place to promote sustainable design, should go further in their promotion.
- It is recommended that the architectural industry, as a whole, not just small architectural practices in Wales are, if they are not a RIBA member, to be required as part of their membership, sign up and participate in the 2030 Climate Challenge.
- A campaign of education into the use and promotion of sustainable design should be aimed at all architect practices, especially small ones. With better

education architects will also be in a better position to inform domestic clients, not only of their obligation to help reduce CO₂ emissions, and the other benefits, such as running costs, of adopting a sustainable design for their project.

- Facts and figure that accurately set out the cost/benefit of sustainable design principles should be widely available to architecture practise so that they help can de-stigmatise the affordability and buildability stigma attached to sustainable design.

Future Research

Future Research could be undertaken to examine the cost in the present day of using a sustainable design, compared to a standard design approach. Not only would it be beneficial to compare standard design to sustainable design as a whole, but comparing the cost of a passive design to active design would lead to a better understanding of the cost impactions of each approach, which can help guide architects to which sustainable approach could offer domestic project the best value for money.

Future research into the savings achieved on a yearly basis by adopting a sustainable approach over a standard approach would be beneficial also. This will help when it comes to promoting a sustainable design option to a domestic client.

Research into the cost of using sustainable approaches in large scale residential development would be ideal, as more and more large-scale residential projects are likely to happen in years to come as more and more housing is required. Therefore, more research is required to better understand the costs of using sustainable approach at large scale could also lead to more mainstream developers utilising sustainable design.

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Appendix A

A1. Break down of types of projects architect carry out in the UK:

- Individual houses, extensions and loft conversions 49%
- Private Housing 16%
- Offices 5%
- Retail 4%
- Leisure 5%
- Industrial 3%
- Health 2%
- Education 5%
- Public Housing 2%
- Other 10% (Construct UK Ltd, 2020)

A2. Stats on RIBA registered practices and practice sizes base on numbers of staff

RIBA	East	269	Amount of staff	Number of practices
RIBA	East Midlands	128	1	890
RIBA	London	1522	2-5	1520
RIBA	North East	68	6-10	649
RIBA	North West	301	11-50	662
RIBA	South	264	51+	126
RIBA	South East	290	Total	3847
RIBA	South West	131		
RIBA	Wessex	229		
RIBA	West Midlands	184		
RIBA	Yorkshire	214		
RSWA	Wales	84		
RIAS	Scotland	85		
RSUA	Northern Ireland	78		
	Total	3847		

Appendix B

B1. National Planning Policy Framework (NPPF)

The NPPF was created by the Ministry of Housing Communities and Local Government and is used to set out Government planning policies for England; it also explains how these policies should be applied. The document was created to provide a framework in which plans for housing and other developments can be formed.

The NPPF is also used when preparing local development plans and is a substantial consideration in making planning decisions. These planning policies also reflect relevant international obligations and statutory requirements with regards to development. Like most other planning policy documents in the UK the NPPF looks to promote sustainable development and has three keys that it identifies at the very start of the document; these are interdependent, however, should be pursued in mutually supportive ways. This is so that the opportunity can be taken to secure net gains across each of them:

1. Economic – to help build a strong, responsive and competitive economy, by ensuring that sufficient land of the right types is available in the right places and at the right time to support growth, innovation and improved productivity; and by identifying and coordinating the provision of infrastructure⁹⁸;
2. Social – to support strong, vibrant and healthy communities, by ensuring that a sufficient number and range of homes can be provided to meet the needs of present and future generations; and by fostering a well-designed and safe built environment, with accessible services and open spaces that reflect current and future needs and support communities' health, social and cultural well-being; and⁹⁹
3. Environmental – to contribute to protecting and enhancing our natural, built and historic environment; including making effective use of land, helping to improve biodiversity, using natural resources prudently, minimizing waste and pollution, and mitigating and adapting to climate change, including moving to a low carbon economy¹⁰⁰.

⁹⁸ (Ministry of Housing Communities & Local Government, 2019)

⁹⁹ (Ministry of Housing Communities & Local Government, 2019)

¹⁰⁰ (Ministry of Housing Communities & Local Government, 2019)

B2. Local Development Plan (LDP)

LDP's are produced by the LPA to set out the strategic priorities for development of an area, typically covering housing, commercial, public and private development. An LDP also includes transport infrastructure, and protection for the local environment. They typically comprise of a series of documents which sets out clear guidance on what development will and will not be permitted in an area.

An LDP should aim to encourage a positive realistic look at development and infrastructure communities need and should set out the strategic priorities for the local area. This should include policies to deliver:

- Housing, including affordable homes;
- Retail, leisure and other commercial development;
- Infrastructure for transport, minerals, waste, energy, telecoms, water supply and sewage treatment;
- Education, health, police and community facilities;
- Energy, including from renewable sources;
- Protection and enhancement of the natural and historic environment, including landscape, wildlife, open space, listed buildings and archaeology; and
- Protection of homes and property from flooding from rivers and the sea.

LDP's should be aspirational, and realistic, in regard to sustainability and address the spatial and land use implications of economic, social, and environmental change. LDP's are used to set out the opportunities for development with clear guidance on what will or will not be permitted and where¹⁰¹.

LDP's set out the broad strategy for development in an area. They cannot state exactly what changes will happen in each area.

Local plans can:

- Identify where development should take place, and when it should happen during the life of the plan;
- Decide the broad type of development that should be provided to meet local needs (e.g. housing, business, leisure, essential infrastructure);
- Mediate between competing demands for different land uses;
- Promote regeneration of town centres, derelict land or other areas;
- Protect special areas of the countryside and important buildings;
- Reduce risks to human health and well-being (e.g. from flooding);

¹⁰¹ (Planning Help, 2020)

- Help reduce the contribution to climate change and ensure new developments are adapted to a changing climate;
- Reduce the need to travel by providing land for homes, schools, shops and businesses in close proximity to each other;
- Be flexible, to suit changing needs of business and communities;

Local plans cannot:

- Ensure developments go ahead once planning permission is granted - this is decided by developers (and influenced by economic conditions),
- Decide in detail which type of shops or businesses are provided (unless there are good reasons to do so);
- Prevent a particular company or person from developing a site;
- Stop businesses, schools or hospitals from closing;
- Decide the quality and frequency of public transport services;

Please everyone, all of the time¹⁰²;

B3. Wellbeing of future Generation (Wales) Act 2015

To help work towards this vision, the Act has seven well-being goals in place these are:

- A prosperous Wales
- A resilient Wales
- A healthier Wales
- A more equal Wales
- A Wales of cohesive communities
- A Wales of vibrant culture and thriving Welsh language
- A globally responsible Wales¹⁰³

The following public bodies were listed in the Act to adopt a more long-term approach, in order to work better with people and communities and each other, in order to prevent future problems and take a more joined-up approach to the future of Wales.

- Welsh Ministers.
- Local Authorities.
- Local Health Boards.
- Public Health Wales NHS Trust.
- Velindre NHS Trust.
- National Park Authorities.

¹⁰² (Planning Help, 2020)

¹⁰³ (Sustainable Development Branch Welsh Government, 2015)

- Fire and Rescue Authorities.
- Natural Resources Wales.
- The Higher Education Funding Council for Wales.
- The Arts Council of Wales.
- Sports Council of Wales.
- National Library of Wales.
- National Museum of Wales¹⁰⁴

¹⁰⁴ (Sustainable Development Branch Welsh Government, 2015)

Appendix C

C1. Calculations of CO₂ Kg/year for every £10,000 of the total build cost

Case study one Elford Road new build

1,461.6Kg/year of CO₂

£250,000 total build cost (CO₂/Cost x 10,000)

58.46Kg/year of CO₂ for every £10,000 (1,461.6/250,000 x 10,000)

Case study two Fernaig Cottage extension

1,955Kg/year of CO₂

£205,000 total build cost (CO₂/Cost x 10,000)

95.36Kg/year of CO₂ for every £10,000 (1,955/205,000 x 10,000)

Case study three Adolphus Road new build

132,724.13Kg/year of CO₂

£240,000 total build cost (CO₂/Cost x 10,000)

5,530.17Kg/year of CO₂ for every £10,000 (132,724.13/240,000 x 10,000)

Case study four The Lodge extension

136,000Kg/year of CO₂

£170,000 total build cost (CO₂/Cost x 10,000)

8,000Kg/year of CO₂ for every £10,000 (136,000/170,000 x 10,000)