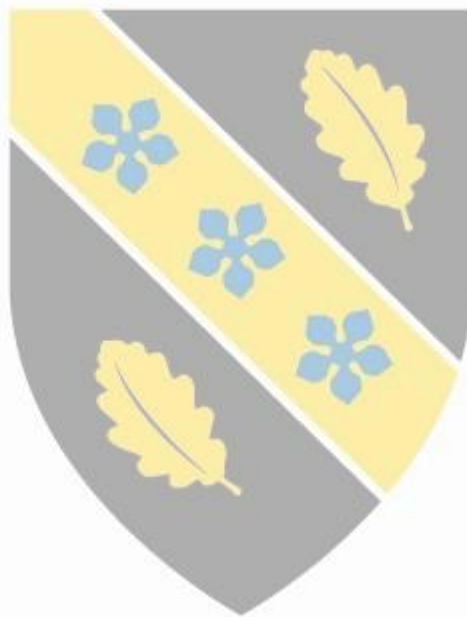

Is the retrofitting of living wall systems on existing building stock a cost- effective way to prevent pluvial localized flooding in UK cities?

By

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Abstract

There is an intensifying pressure on dense urban areas to employ Sustainable Urban Drainage Systems (SuDS) such as Modular Living Wall Systems (MLWS) to mitigate the effects of localised pluvial flooding. Architects, engineers and clients alike are searching for assurances that the system has measurable cost and performance benefits during its life cycle. Marching toward legitimacy, MLWS's have gradually become scrutinized. Further understanding is required in establishing living walls as a viable SuDS option. Intricacies interlinked to retrofitting MLWS's include ensuring an appropriate support structure and not to mention affordability, sustainability and longevity.

Fulfilling these complexities - conquering all these factors - will be indispensable for MLWS's to mature beyond their use as vanity projects and gain acceptance as a forthright SuDS technology by the construction industry. The compatibility potential of fusing MLWS's with existing building stock through retrofit has generated little literature, particularly within the UK. Questionable, is the lack of associated government-backed incentives. Would these enticements be necessary? Similarly, would MLWS's prove cost-effective to the prospective client and government alike? Will this mechanism improve adaptation holistically and promote a downward trend in unit costs?

This dissertation therefore aims to aid these paradigms by enhancing the growing relevance of the sustainability agenda to the professions of the built environment. Firstly, by gauging that mandates at an educational level - particularly at university level, are fit for modern-day purpose. This has been accomplished through a triangulated analysis approach, applying interview and questionnaire fieldwork to measure the evident attitudinal disparities between construction professionals (CP's) and Construction Students (CS's), permitting a critical analysis of the barriers and opportunities afforded by implementing sustainability to transpire.

Secondly, architects, designers and clients in tandem can find themselves sifting through an abundance of conflicting information regarding MLWS's. Therefore, professional guidelines have been articulated upon the information relayed to the researcher contained by the interview fieldwork. Constructed, is a comparative table illustrating the difference in performance between retrofitting MLWS's and other flood remediation technologies. The development of a mathematical formula predicting how much pluvial rainwater and a retrofitted MLWS can take out of the local environment has helped promote this.

Lastly, by employing this formula, a simulation of mass living wall retrofit across the Borough of Kensington and Chelsea had been permitted to enable a tabulated cost-comparison study. Results suggest that retrofitted MLWS's would be a more economical opportunity in contradiction of the infrastructure upgrades currently taking place at the London Tideway Super Sewer Project (LTSSP). Limitations of this research include the researcher's inability to perform laboratory work, owing to technological limitations. Furthermore, the provocation of the COVID-19 pandemic barred supplementary qualitative fieldwork from taking place.

To further the work of this academic dissertation the researcher recommends that the prerequisite of including the studying of MLWS's in further education should be surveyed. Additionally, future development of the devised mathematical formula should ensure the inclusion of the additional influences of, orientation, temperature, evaporation and flora variation upon the efficiency of living wall systems. In conclusion, supplemental exploration into generating a London-wide cost comparison would be beneficial to set a MLWS cost benchmark for future large-scale sewer infrastructure projects around the world.

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List of Abbreviations

Abbreviation Clarification

<i>UK</i>	United Kingdom
<i>LTD</i>	Limited
<i>UWTSD</i>	University of Wales Trinity Saint David
<i>PLC</i>	Public Limited Company
<i>IMPACT</i>	Institute for Innovative Materials, Processing and Numerical Technologies
<i>MLWS</i>	Modular Living Wall System
<i>UPFR</i>	Urban pluvial flood risk
<i>°C</i>	Degrees Celsius
<i>TTT</i>	Thames Tideway Tunnel
<i>KM</i>	Kilometres
<i>L</i>	Litres
<i>UKGBC</i>	UK Green Building Council
<i>CO₂</i>	Carbon Dioxide
<i>BC</i>	Before Christ
<i>CF</i>	Climbing Facade
<i>LW</i>	Living wall
<i>pH</i>	Pondus Hydrogenii
<i>mm</i>	Millimetres
<i>DPM</i>	Damp Proof Membrane
<i>M</i>	Metre
<i>CBA</i>	Cost-Benefit Analysis
<i>NPV</i>	Net Present Value
<i>IRR</i>	Internal Rate of Return
<i>PBP</i>	Pay Back Period
<i>ROI</i>	Return on Investment
<i>EU</i>	European Union
<i>SUDS</i>	Sustainable Urban Drainage Systems
<i>CSO</i>	Combined Sewer Overflows
<i>DEFRA</i>	Department of the Environment, Fisheries and Rural Affairs
<i>CIWEM</i>	Chartered Institution of Water and Environment Management
<i>SGIS</i>	Skyrise Greenery Incentive Scheme
<i>CCC</i>	Committee on Climate Change
<i>COVID-19</i>	Coronavirus
<i>SPSS</i>	Statistical Package for Social Sciences
<i>FM</i>	Facilities Management
<i>NHS</i>	National Health Service
<i>MEWP</i>	Mobile Elevating Working Platform
<i>PV</i>	Photovoltaic
<i>GLA</i>	Greater London Authority
<i>CP</i>	Construction Professional
<i>CS</i>	Construction Student
<i>P-P</i>	Probability – Probability
<i>LTSSP</i>	London Tideway Super Sewer Project

Nomenclature

Abbreviation Clarification

AVG_{PR}	Tonnes of average monthly pluvial rainwater in the borough
AVG_{CSO}	Tonnes of average monthly CSO's in the borough
MT_{PR}	Monthly deduction of pluvial rainfall required for zero CSO spill
DT_{PR}	Daily deduction of pluvial rainfall required for zero CSO spill
Tm^2	Total m ² of MLWS required
TC	Total cost
MLO	Orientation
MLT	Temperature
LWE	Evaporation
$LWFFV$	Flora variation

Chapter 1 – Rationale for the Research

The subject for this research is developed from a personal interest in the dichotomy between sustainable construction and the axiomatic gap in UK standards and expertise concerning Modular Living Wall Systems (MLWS's). The foundations for this research have been defined by the work of (Riley, 2017) which cohesively assess the rewards and criticisms of MLWS's; amalgamating with government guidance *Living Roofs and Walls - Technical Report: Supporting London Plan Policy* focusing specifically upon the adaptability of MLWS's within London. Presently, the UK's larger urban areas are struggling to deal with increasing drainage volumes as a result of climate change and expanding inner city populations. According to United Nations research, 66% of people will live in urban areas by 2050 (*World Urbanization Prospects, 2014*).

Urban pluvial flood risk (UPFR) is caused by severe, prolonged rainfall which overwhelms the capacity of the drainage system; a principal hazard facing modern cities. This type of flooding regularly leads to major economic losses and destructive socio-environmental impacts. Pluvial floods can wield significant pressure on urban sustainability and human wellbeing during rapid urbanization (*Shiqiang Du, 2019*). Within the UK, approximately 2.4 million properties are at risk today from fluvial flooding from rivers and the sea, and around 3 million properties are at risk from UPFR (*Environment Agency, 2019*). Two sources, namely (*Swan, 2010*) and (*Semadeni-Davies et al., 2008*) agree that extensive urban in combination with insufficient sewer systems and climate change aggravates the problem.

Between 2010 and 2020 the UK has seen a massive increase in flooding, as set out in the government guidance (*National Flood Resilience Review, 2016*). Furthermore, Met Office records demonstrate that since 1910 there's been 17 record breaking rainfall months with 9 eventuating since 2000. As intense storms are becoming more frequent, sea levels are equally rising as a symptom of climate change. On current trends, global temperature could rise between 2°C and 4°C by 2100 and £1bn a year would need to be spent on flood management (*Harrabin, 2019*).

In London predominantly, UPFR is expected to increase significantly as a result of climate changes and demographic shifts: the former is likely to increase the magnitude and frequency of extreme storm events, the driving force of pluvial flooding, while the latter will increase exposure (*Urban Flooding, 2020*). Amalgamating this UPFR with the millions of tonnes of raw sewage and rainwater currently overflowing into the River Thames each year owing to Sir Joseph Bazalgette's Victorian sewer network reaching maximum capacity, a real urban challenge is surfacing. The Thames Tideway Tunnel (TTT) or 'London Super Sewer Project' is a £5bn answer to London's sewage and rainwater issues; stretching 25km under the Thames to intercept, store and convey raw sewage and rainwater to Beckton Treatment Works in East London.

Research engineered by (*Katja Hüve, 2011*) reveals that MLWS's have the capability of eradicating up to 1L of rainwater per m²/day from the local environment, this data therefore suggests that pluvial flooding could be dealt with at the source, rather facilitating the need for multi-billion-pound upgrades. The outcomes of this research intend to highlight the full potential of MLWS's, with anticipation of making a case for government-backed incentives and compulsory adaptation on government funded buildings.

So, what if MLWS's were designed for retrofit onto existing building stock within the UK to help deal with drainage difficulties? If they were standardised in the building regulations, would this make constructors less wary of them? In addition, would the implementation of MLWS's in London principally be a cheaper and more sustainable alternative to drainage upgrade projects such as the £5bn TTT? The conclusion from this investigation could have profound implications on how constructors view living wall systems and how likely they will be to adopt the system to counteract the effects of increased pluvial flooding moving forward into the new decade.

1.1 Research Goals

The aim of this research is to:

Evaluate whether the retrofitting of living wall systems on existing building stock is a cost-effective way to prevent pluvial localized flooding in UK cities.

The objectives of this research are threefold:

1. To recognize the attitudes of construction professionals towards the retrofit on MLWS's as a flood remediation technology and to interpret how their expertise diverge from construction undergraduates.
2. To provide professional guidelines to design managers who are required to design and retrofit MLWS's through constructing a comparative table showing the difference in performance between retrofitting MLWS's and other flood remediation technologies. The development of a mathematical formula to predict how much pluvial rainwater and a retrofitted MLWS can take out of the local environment will help promote this.
3. To evaluate the cost of MLWS's per m² to the alternative technologies currently being installed at the London Tideway Super Sewer and to additionally critically appraise if imposing MLWS's compulsory on all new government funded projects would help lower the costs of the system, as well as making a case for government-backed incentives.

1.2 Chapter Structure

Chapter 1: Introduction

Chapter 2: Literature Review into the Drivers and Barriers of Living Wall Adaptation

Chapter 3: Research Design and Methodology

Chapter 4: Results and Analysis

Chapter 5: Conclusions and Recommendations

Chapter 6: References

Chapter 7: Appendices

1.3 Initial Research Methodology

The scientific and psychosomatic paradigms of MLWS benefits and the entrenched objections to the technology being a flood remediation mechanism will be surveyed through quantitative questionnaires and further triangulated by structured qualitative attitudinal interviews with construction undergraduates and practicing professionals. The application of Spearman's risk coefficient (ρ) definition of X will be manipulated to summarise the strength and direction (negative or positive) of a relationship between two variables within the questionnaire analysis. Thematic analysis of interviews will be inaugurated, where the researcher will firstly assign preliminary codes to the data in order to describe the content. Secondly, search for patterns or themes in the codes across the different interviews. Thirdly, review themes. Fourthly, define and name themes, before finally producing an explanatory report of the results.

Non-random purposive sampling the UK-based construction undergraduates and practicing professional's demographic is justified by all correspondents having the idiosyncrasy of being within the construction industry at a management or undergraduate level, where all contributors will have an underlying knowledge of MLWS's, detailed knowledge of structural forms and building physics associated with retrofit, sustainability, existing government framework, building standards and cost intricacies essential to fulfilling the research objectives.

Chapter 2 – Literature Review into the Drivers and Barriers of Living Wall Adaptation

2.1 Scope of Chapter

This chapter critically appraises the literature review, identifying the similarity of statements; common themes; differences and contradictions of the body of evidence. It is divided into seven segments, comprising: 1) Definition of sustainability; 2) History background; 3) Barriers to adapting living wall technology; 4) Benefits of MLWS's; 5) Urban pluvial floor risk (UPFR) in London; 6) London Thames Tideway (TTT) Super Sewer Project, and finally; 7) Critical appraisal of the chapter.

2.2 Definition of Sustainability

The question of sustainability has generated an expanse of literature, especially over the past two decades. It is a broad term describing a desire to carry out activities without exhausting resources or inducing harmful impacts, it is defined by the *Brundtland Commission* as '*meeting the needs of the present without compromising the ability of future generations to meet their own needs.*'

2.3 Historical Background

Modular Living Wall Systems (MLWS's); otherwise known as *vertical gardens* or *green facades* are terms which are used to refer to all forms of vegetated wall surfaces. Throughout history traces of the use of vegetation in an urban context appear, at the very beginning of civilisation, the hanging gardens of Babylon (*Figure 1*) were said to be built by King Nebuchadnezzar II in 600 BC to relieve the depression of his wife, homesick for her green homeland.



Figure 1: *Hanging Gardens of Babylon illustration (Cartwright, 2018).*

Fast forward approximately 1000 years to the Viking Period, where Icelandic Vikings utilised turf, a top layer of soil consisting of plants and roots to cover the facades and the rooftops of their houses to resist inhospitable weather conditions (*Figure 2*).



Figure 2: Modern day turf houses in Keldur, Iceland (Hronn, 2018).

The MLWS concept incorporating irrigation systems was developed in the 1940's by Stanley Hart White, a professor at the University of Illinois. However, the most notable creator of LW's in the last two decades is Parisian Architect, Patrick Blanc, who is often credited with inventing the irrigation concept before Professor White's work became well known. Blanc has created many innovative MLWS's in locations around the world and authored several books on tropical plants. Blanc's most notable MLWS's include the Lafayette Galleries in Berlin (*Figure 3*) and the French Embassy in New Delhi.



Figure 3: The Lafayette Galleries in Berlin (Matthews, 2017).

Today, MLWS's can be effectively incorporated into many kinds of settings, including office buildings, shopping centres, and even homes. However, they are intended for use in flag-ship new-build construction and not for the purpose of retrofit. Literature upon the proposition of retrofitting MLWS is extremely limited, however a journal composed by (Perini, 2013) presents a MLWS retrofit project in Genoa, Italy. The 3-storey residential structure dates to the sixties, possessing serious architectural and efficiency problems.

2.4 Barriers to Adapting Living Wall Technology

This research focuses primarily upon retrofitted MLWS's which are constructed from modular panels, each one containing its own artificial growing medium such as foam, felt, perlite, and mineral wool, employing automated irrigation systems to provide all or part of plant's food and water requirement (Dunnett et al., 2008). MLWS's can also be indirect (façade supported) or direct (façade integrated) where the MLWS panel is a physical part of the external cladding

(UrbanGreening, 2017). The architectural, structural and expenditure challenges associated with MLWS's have been highlighted in research published by Benjamin Riley.

"Satisfying these complex needs - mastering all these factors - will be essential for living wall systems to mature beyond their use as vanity projects and gain acceptance by the construction industry" (Riley, 2017).

2.4.1 Structural Appraisal of MLW's

As part of this research, the researcher has self-assembled MLWS case studies from around the world, illustrating primary evidence of prosperous retrofitted systems in some of the world's most preternatural climates. The stresses these retrofitted MLWS's are coercing upon the structures is outlined in red and highlighted with arrows on *Figures 4 & 5* and subsequently expounded.

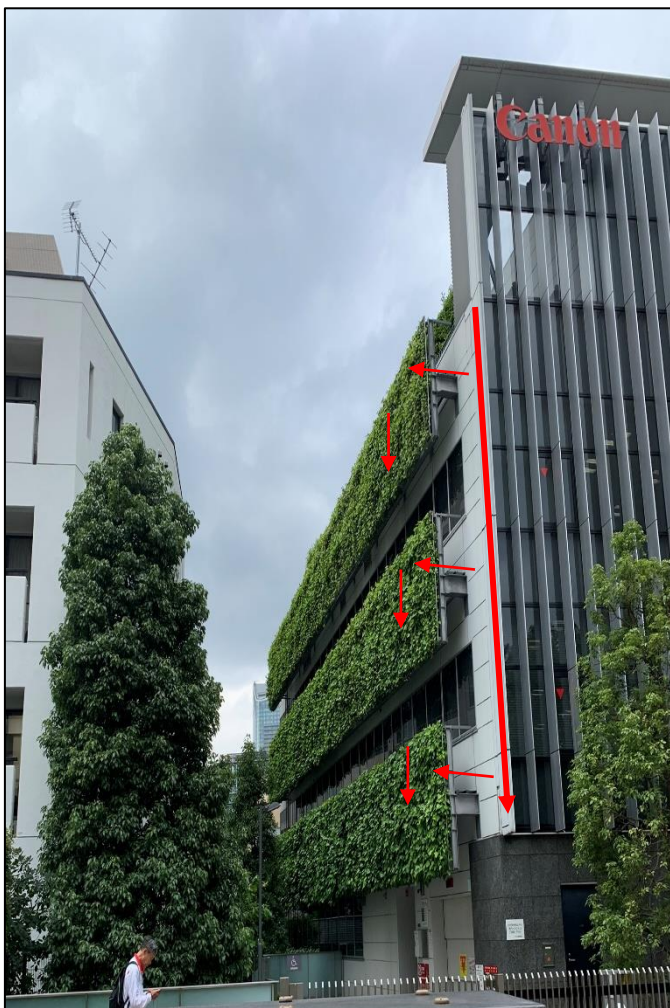
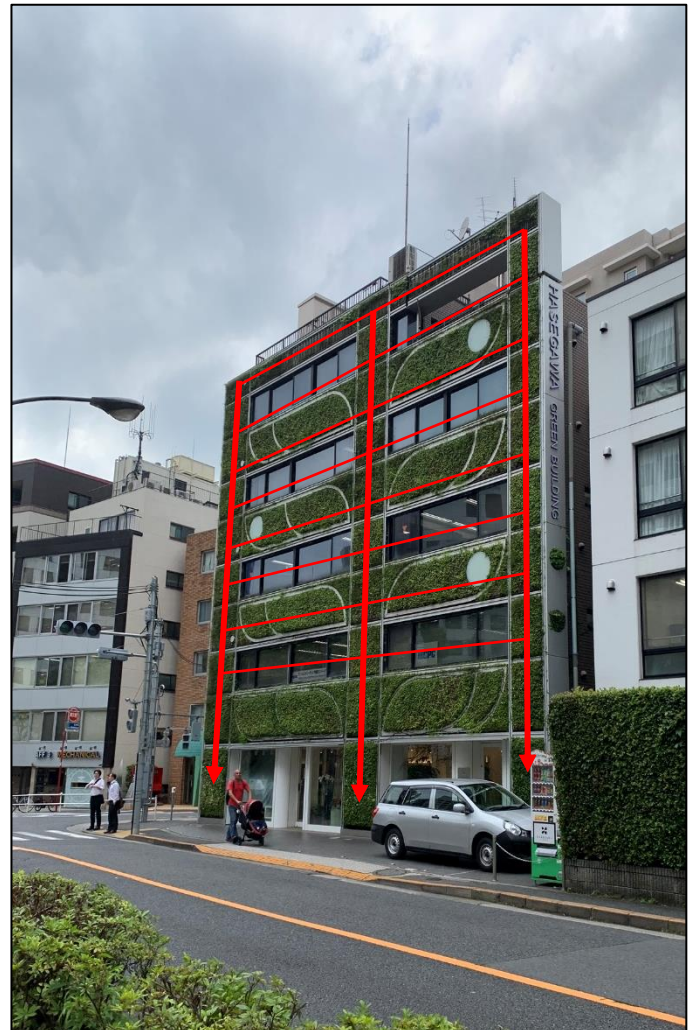


Figure 4: Canon Inc. Headquarters, Tokyo (Author, 2019)

Figure 5: Hasegawa Green Building, Tokyo (Author, 2019)



At the Canon Inc. Headquarters, the MLWS has been retrofitted using the pre-existing steel beams that once supported an external cladding system. The mass of the MLWS is therefore transferred into the structure across the beam and down to the ground in a cantilever.

“Cantilever structural forms occur when beams supported at one end and carrying a load at the other end or distributed along the unsupported portion. The upper half of the thickness of such a beam is subjected to tensile stress, tending to elongate the fibres, the lower half to compressive stress, tending to crush them” (Cantilever, 2016).

The Hasegawa Green Building located only a few yards from Canon in the vicinity of Tokyo Tower has also incorporated a retrofitted MLWS. A corporate social responsibility official of Hasegawa stated to the Japan Times *“we created the greenery area as we aimed to make our office a place accepted by residents, and we now see a lot of birds coming” (Kimura, 2017)*. Structurally speaking, Hasegawa transfers the load of its MLWS to the ground differently, being directly attached to the cladding rails of the building. Therefore, the load is shared more equally across the wall junctions and window sections.

Through contrasting these two approaches to MLWS load dispersion, many disparities can be observed. The system adopted at Canon Inc. Headquarters allows approximately a 1500mm gap between MLWS and the perpendicular face of the structure, this makes the system separate from the building and therefore thermal benefits are minimal in comparison to that at Hasegawa.

2.4.2 Flora and Fauna & Biodiversity

Constructed by Kier Construction LTD and handed over in May 2019, Swansea Universities IMPACT building accommodates a 114m² MLWS on its North elevation. The MLWS, assembled by Biotecture LTD amounted to costs narrowly surpassing £70,000, nearly £615/m² (Figure 6).

Swansea Universities justification for necessitating a MLWS on IMPACT was owing to the locality of the development as well as preserving biodiversity in the area. Biodiversity is the assortment of life in a habitat or ecosystem. It includes species diversity, ecosystem diversity and genetic diversity. Crumlyn Burrows, a designated Site of Special Scientific Interest (SSSI) is approximately 100m from the structure, encompassing the need for the client to drive biodiversity (Sullivan, 2019).



Figure 6: Preservation contractor Biotecture LTD using a scissor lift to perform maintenance on the MLWS at IMPACT (Author, 2019).

Ben Sampson, Swansea University Biodiversity Officer, said:

“As well as being a striking approach to campus, the living wall will improve the building’s energy efficiency and provide a home for wildlife. With Crumlyn Burrows Site of Special Scientific Interest next door, we had to be especially careful to select plants that would not invade the dunes and cause problems in the natural environment too” (Sullivan, 2019).

Further complications associated with the MLWS’s flora remain the irrigation system, oxygen, nutrients and pH levels in addition to the three main climatic factors to consider when designing MLWS’s; temperature, wind, and orientation (Goodwin, 2015). Inept to cold weather survival, there are instances in which all the plants have perished during the first winter (Dvorak, 2015). Conversely, plants will not “drink” when it is too hot (Hüve, 2011) or if the pH levels are incorrect (Crawley, 1987). Suchlike, Figure 7 illustrates all variations of flora fused into the 114m² ecosystem at IMPACT, these carefully selected plants can survive South Wales seasonal climatic changes.



Figure 7: Flora incorporated into Swansea Universities IMPACT building MLWS (Biotecture, 2018).

The irrigation system is conceivably the most important part of a MLWS, it is devised to provide plants the nutrients they require to survive. On today's market the most efficient living wall exterior systems consume 1L of water per m²/day (*Hydroponics for Living Walls*, 2014). Systems can be created to reduce the overconsumption of potable water by harvesting rainwater runoff from the structures roof (Loh, 2008), which can be concurrently beneficial for flood management; a challenge which large UK cities are striving to deal with.

"Urban development can have a significant impact on our natural habitats. With habitat modification having been identified as one of the most important drivers of biodiversity loss, the urban environment is becoming an increasingly expanding geographical area that could be used to support wildlife. From the introduction of green infrastructure, to the engagement and active participation of local communities and city residents, there are numerous ways in which the urban environment can be developed to promote the integration of biodiversity" (Biodiversity in Building Design and Construction, 2020).

2.4.3 Existing UK Legislative Framework

The omission of a British Standard is often cited as a real barrier to whole-scale uptake of MLWS's and as such the resistance in integrating such technology within the built environment is systemic, such as entrenched perceptions about the incompatibility of natural and urban systems (Birkeland, 2009). Leading researchers in sustainable construction (Charoenkit, 2016) and (Pradhan, 2019) agree that additional justifications for the lack of uptake of retrofitted MLWS's comprise:

- Absence of demonstrated living wall projects,
- Lack of awareness of LW design in general,
- The emphasis on reducing impacts instead of health improvements,
- Inadequacy of codes and regulations in supporting urban innovation,
- Lack of government support (i.e. tax, loans, subsidies) for living systems.

Yet, there is no explicit statement of national policy requiring or encouraging the use of MLWS's. Historically, national strategies such as the *UK government's sustainable development strategy*

(2005) and *Climate Change: the UK Programme* (2006) have failed to recognise MLWS's potential in the regard to sustainability and climate change respectively. However, of late government guidance documents; the *London Sustainable Drainage Action Plan* (2016) and *London Environment Strategy* (2018) have begun to change prospective on this area, alluding to the prospect of London becoming: *"the world's first National Park City where more than half of its area is green; where the natural environment is protected and the network of green infrastructure is managed to benefit all Londoners"* (Sadiq Kahn, 2018).

2.4.4 Affordability, Sustainability & Longevity

Cost is the greatest factor thwarting living wall proliferation. Locating standardised published costs is challenging, partly because there is not a one-size-fits-all solution, so costs are adapted to each project and thus vary widely (Perini, 2011). An MLWS can cost anywhere from £1000 upwards of £250,000. To avoid sticker shock *"shock or dismay experienced by the potential buyers of a product on discovering its high or increased price"* (Oxford Dictionary, 2019) living wall contractors abstain from publishing cost estimates.

Maintenance Costs

The initial capital investment of MLWS are high when compared to other exterior cladding systems such as curtain walling of timber (Ottelé, 2011). Additional research conducted by (Katia Perini, 2013) distinguishes the maintenance of a MLWS to be 8.5% of the installed cost, whereas research completed by (Mathew 2014) places that figure upward of 15%. Biotecture Project Manager, Steve Borman describes that often maintenance upon a MLWS is contracted separately; meaning the installer may not have to be responsible for the success of the wall beyond the warranty period, causing further cost ambiguity. Through Steve's time at Biotecture he has also witnessed clients surprised by the service costs associated with maintaining an MLWS.

Short-term Investment vs Cost-Benefit Analysis (CBA)

For a MLWS to be financially viable the short-term investment needs to be appropriated by equal or superior benefits in cost saving, this is concluded through cost-benefit analysis (CBA). The economic sustainability of each MLWS is calculated by way of three indicators:

- 1) Net Present Value (NPV), i.e. the sum of costs and benefits that occur within the period of life considered.
- 2) Internal Rate of Return (IRR), i.e. the annual percentage rate of return on investment.
- 3) Pay Back Period (PBP), i.e. the number of years from which the total revenue equals (or exceeds) for the first time the total costs.

Research presented by Sean Farrell of Staffordshire University declares that for MLWS's to be affordable, many experts agree the "ignition point" to adaptation is approximately half the current cost of a MLWS. For example, in the UK estimates currently range from 350 to 600£/m², whereas 200£/m² is considered the "tipping point" of affordability. Farrell suggests that to reduce both short-term and long-term costs the most-likely avenues are innovation, tax incentives, and government subsidies, towards the goal of attaining economies of scale; of which are presently unobtainable in the UK.

2.5 Benefits of MLWS's

It is widely adjudged that LW's can form an important element of sustainable building by reducing the risk of surface flooding, reducing the extremes of temperature fluctuation and by enhancing the biodiversity of the locality (*Gunnell, 2013*).

2.5.1 Acoustics

There has been strong evidence articulated that flora within MLWS's can absorb a considerable proportion of the energy in the incident sound wave. This can be extremely beneficial in environments with infrastructure noise surrounding a property. Research concluded by (*Anna Romanova, 2019*) signifies this statement through the formation of in-situ analysis.

2.5.2 Thermal Transmittance

Many MLWS manufacturers affirm that the systems reduce the heating requirements of the building, but a lack of data exhibiting by how much precisely can alert potential suiters (*Marie-Therese Hoelscher, 2016*). Investigations undertaken by the Vienna University of Technology assume the total thermal resistance value of a MLWS to be $0.52 \text{ m}^2\text{K/W}$ when calculating prospective energy savings within a case study. In Layman's terms, this means that a façade is insulated better by the resistance of $0.52 \text{ m}^2\text{K/W}$. Rationally, the variation of the physical characteristics of the MLWS mean this resistance can change considerably case study to case study.

MLWS's have been explored to reduce energy costs in buildings; ranging from £0.71/week (*Antonyová, 2017*) to £19/week per m^2 (*Manso, 2016*) where discrepancies in the climate, materials and analysis methodology occur. Holistically the literature agrees that the inclusion of MLWS improves thermal comfort of indoor spaces, however, this benefit is offset by the reality that an industry-backed standardised method of how to calculate the U-values of MLWS's is non-existent (*V. Oquendo-Di Cosola, 2019*).

2.5.3 Fire Resistance

On the 14th June 2017 significant events took place at a residential tower block in the Borough of Grenfell, London and from which fierce condemnation has been assembled against the use of external cladding systems and their combustible properties. Published in October 2019, *The Grenfell Tower Inquiry: Phase 1* established a new vision upon the use of external cladding systems. Grenfell is highly important to the future use of MLWS's as it is a leading instance of retrofitted erroneous cladding systems architecturally, materially and quality wise. Too add uncertainty, guidance available upon the design and construction of MLWS's from UK sources is extremely limited and primarily derives from the United States or mainland Europe (*Gedge, 2008*).

2.5.4 Health & Well-being

Urbanisation correlates in conjunction with increased risk of psychosis 72% and depression 16% (*Sundquist et al., 2004*). Whereas, studies also indicate that the productivity of workers increases by as much as 23% in offices with indoor green (*Bergs, 2002*). Green spaces induce direct health benefits to patients in hospitals, clinics and other caring institutions. The biophysical benefit of visual and physical contact with nature can reduce stress and provide higher resistance to illness (*Wells et al. 2000*). Whilst most biogenic processes of plant life are firmly considered as a positive influence, some characteristics can pose challenges to human comfort and health. These include CO_2 discharges from plant respiration, humidity, and expulsion of allergens, and toxins (*Kanchane Gunawardena, 2019*).

2.6 Urban Pluvial Flood Risk (UPFR) in London

Urban pluvial flood risk (UPFR) is caused by severe, prolonged rainfall which overwhelms the capacity of the drainage system; a principal hazard facing modern cities (*Urban Flooding*, 2020). This type of flooding regularly leads to major economic losses and destructive socio-environmental impacts. Pluvial floods can wield significant pressure on urban sustainability and human wellbeing during rapid urbanization (*Shiqiang Du*, 2019). Within the UK, approximately 2.4 million properties are at risk today from fluvial flooding from rivers and the sea, and around 3 million properties are at risk from UPFR (*Environment Agency*, 2019). Two sources, namely (*Swan*, 2010) and (*Semadeni-Davies et al.*, 2008) agree that extensive urbanisation in pattern with inadequate sewer systems and climate change aggravates the problem. Illustrated in *Figure 8* is the current extent of UPFR in the Borough of Kensington and Chelsea, London, where in some places, entire communities retain this risk.



Figure 8: Stressed in **BLUE** is the flood risk from pluvial surface water within Kensington and Chelsea (*Flood Warning Information Service*, 2020).

2.6.1 Existing UK Housing Stock Adaptability

In most EU countries, many buildings were constructed before standards were introduced, in the UK, over half of the residential stock has been built before 1970 (*VOA*, 2018). The performance of buildings depends on various factors such as climatic conditions, building envelope, the state of the installed systems, behaviour characteristics of occupants and social conditions (*BPIE*, 2011). There is much debate about how much building energy consumption savings could be accomplished through deep retrofitting of the EU building stocks, however research by (*London Environment Strategy*, 2018) places this figure at nearly 33%.

In Central London primarily the highest concentration of ageing builds exist, exhibited in *Figure 9* roughly 60% of dwelling structures alone pre-date 1945 (*Ashby*, 2015). When this graphic is superimposed with pluvial floor risk maps as of that shown in *Figure 8*, it is clear to see a correlation between London's earliest structures and increased pluvial flood risk. Therefore it can be deduced that much opportunity exists to retrofit these properties in order to counteract the affects of increased flooding (*Kaveh*, 2018). As aforementioned, constraints to these adaptations include; financial viability, incentives, planning constraints and an industry perception that barriers outweigh drivers.

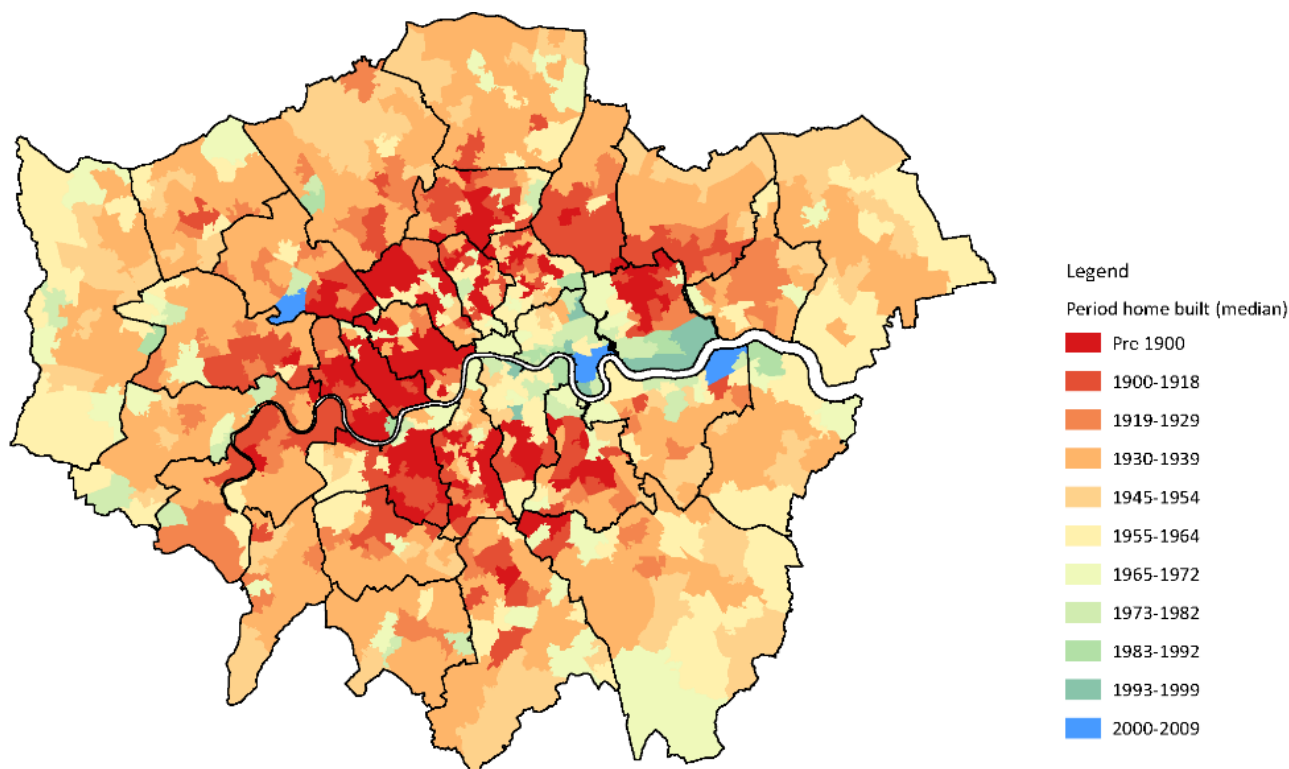


Figure 9: Categorization of the dwelling stock construction periods in London (VOA, 2015).

2.6.2 Alternative Flood Prevention Technologies

Sustainable drainage supports the capture, use, delay discharge or absorption of surface water and can be planned into new urban developments or retrofitted (*Sustainable Urban Drainage Systems (SuDS)*). SuDS have multiple benefits, including:

- Reducing flood risk in urban areas,
- Improving water quality in rivers,
- Increasing biodiversity,
- Improving the public amenity value of a site by creating green corridors through the urban environment.

Table 1 highlights other technological advancements that endorse SuDS's.

Table 1: Summary of selected sustainable drainage technologies (London Sustainable Drainage Action Plan, 2016).	
Technology	Description
Rainwater harvesting	Capture of rainwater into a tank(s) for use in irrigation, toilet flushing, vehicle or plant cleansing.
Storage tanks	External storage tanks which attenuate rainwater for later slow release back into the drainage system.
Swales	Dry ditches used as landscape features allow the storage, carriage and infiltration of rainwater. Best situated alongside roads, or footpaths, they can also be integrated into the design of many open spaces.
Permeable pavements / surfaces	Permeable hard surfaces which work in much the same way as traditional surfaces apart from the ability to allow rainwater to filtrate through (i.e. permeable roads and footpaths).
Oversized piping	Using larger than necessary pipework creates more room to store rainwater. Potentially more sustainable than storage tanks if the pipes drain by gravity and do not require pumping.

Retrofitting SuDS's across London

Through London's planning system, new developments will bring a continual increase in the number of SuDS implemented. However, new development typically affects only around 0.5 per cent of land each year (*London Sustainable Drainage Action Plan, 2016*). Therefore, any big change in the uptake of sustainable drainage requires retrofit on existing properties.

2.7 London Thames Tideway Tunnel (TTT) Super Sewer Project

In 2014, the Government gave consent for the construction of the Thames Tideway Tunnel (TTT). Construction began in 2016, with the project considered necessary to tackle the current problems of combined sewer overflows (CSO's) where currently millions of tonnes of raw sewage overflows into the Thames river every year due to the sewer reaching its maximum capacity. The £4.2 billion project set up to construct a new 'super sewer' to serve London's growing population and to prevent sewage overflow polluting the River Thames will be delivered over an eight-year period, across multiple construction sites in central London.

"It may be hard to believe, but until the tunnel is built, we are treating the river like a toilet. Raw sewage flows directly into the Thames when it rains, as this is the only way to stop homes and streets from flooding when the existing Victorian sewers overflow" (Tideway Spokesperson, 2019).

2.7.1 Financial Implications

According to an CBA commissioned by the Department for Environment, Food and Rural Affairs (DEFRA) the projected benefits from the project will largely exceed the costs (based on a 120-year economic life of the project). While whole life costs are calculated to be around £4.2 billion, the whole life benefits are expected to range between £7.4 and £12.7 billion. Thames Water's argument against the alternative use of SuDS is that such initiatives would never have been enough to alleviate the problem of restricted sewer capacity. Instead, they claim that the maximum practicable level of retrofit SuDS would take over 30 years (DEFRA, 2013) to implement and cost an estimated £13 billion (Thames Water, 2012).

The gauge of the huge sewer is necessary, said Thames Water engineer Phil Stride; *"It ranks with the building of the underground, Crossrail and the Channel tunnel itself. But it will solve the problem of pollution in the Thames for 100 years. Now, 39m tonnes of sewage goes into the Thames every year; this tunnel will collect 96% of it."* However in condemnation, the chair of the Public Accounts Committee in the House of Commons, Margaret Hodge, characterised the project, claiming it to be *'a big vanity infrastructure project'* and a *'gold-plated solution that will lumber London water tax payers with a £80-a-year extra bill'*.

2.8 Critical Appraisal of Literature

Whether MLWS cost is a driver or barrier is one of the most debated topics within the literature. Some academics proclaim that there is real demand for sustainable retrofit of the MLWS and that major clients are driving a green agenda. However, there is a similarly strong counterargument that many clients are debating sustainability but are not implementing this into any of their projects; changing this mindset requires profound structural deviations in a company's socio-economic and institutional arrangements and is an important challenge to the built environment.

Similarities

In statements made by preceding scholars into the subject of MLWS's, numerous similarities have been identified with the common issues stagnating adaptation, these include:

- Absence of living wall demonstration projects,
- Initial design and construction costs,
- Lack of incentives in eco-logical design,
- Lack of awareness of MLWS design in general,
- The focus on reducing impacts instead of health improvements,
- Inadequacy of codes and regulations in supporting urban ecology,
- Lack of government support, such as loans for living systems,
- Lack of procurement systems to ensure quality components,
- Risk aversion and the perceived lack of client demand by developers,
- Scepticism about the cost and value of living systems in urban areas,
- Industry inability to comprehend the value of living things with numerical representations.

Additionally, another trend has been identified with academics recognising the benefits of incorporating MLWS's within structures; namely agreeing upon the health & wellbeing, energy saving, acoustic, thermal insulation and biodiversity subsidies.

Differences

In contrast, as previously emphasized by the UKGBC, the UK construction industry contributes around 45% of the UK's carbon footprint, but judgment varies over the built environment industry's responsibility to address this energy 'in use'. A conflict in opinion has also been revealed in whether London's TTT is 1) value for money, and 2) if greener alternatives were both structurally and practically feasible prior to planning acceptance. Another school of thought highlights that a difference of opinion is consistent between both environmentalists and built environment scholars respectively when assessing their views regarding MLWS's; namely upon their cost effectiveness and their contentions for government incentivisation.

Criticisms

The focus of the academic literature is often based upon large scale, new build projects where lessons can not necessarily be transferred to the retrofit clientele. Additionally, the issue of sustainable retrofitting existing building stock within the UK receives much less attention within the research sector.

Chapter 3 - Research Design and Methodology

Research design is an action plan for getting from 'here' to 'there' where 'here' is the unsolved question and 'there' is a definitive conclusion. Between 'here' and 'there' may be found several key steps, including the collection and analysis of relevant data (Yin, 1994).

This chapter will review the various approaches to data collection. Explaining firstly the difference between qualitative and quantitative research methodologies. Secondly, explaining the differential strategies of data collection, commonly defined as 'fieldwork', before justifying the chosen survey and analysis approach. The contents of Chapter 3 are defined below:

1. Introduction to Research Methodology
2. Research Strategies
3. Fieldwork Research
4. Sampling
5. Outline Methodology
6. Problems and Limitations
7. Research Roadmap
8. Plan of Work

3.1 Introduction to Research Methodology

The aim of this research is to:

Evaluate whether the retrofitting of living wall systems on existing building stock is a cost-effective way to prevent pluvial localized flooding in UK cities.

The objectives of this research are threefold:

1. To recognize the attitudes of construction professionals towards the retrofit on MLWS's as a flood remediation technology and to interpret how their expertise diverge from construction undergraduates.
2. To provide professional guidelines to design managers who are required to design and retrofit MLWS's through constructing a comparative table showing the difference in performance between retrofitting MLWS's and other flood remediation technologies. The development of a mathematical formula to predict how much pluvial rainwater and a retrofitted MLWS can take out of the local environment will help promote this.
3. To evaluate the cost of MLWS's per m^2 to the alternative technologies currently being installed at the London Tideway Super Sewer and to additionally critically appraise if imposing MLWS's compulsory on all new government funded projects would help lower the costs of the system, as well as making a case for government-backed incentives.

3.2 Research Strategies

Research strategy can be defined as a way in which research objectives can be questioned. Commonly, there are two forms of obtained data, namely 'primary' and 'secondary'. In summary, primary data or 'raw data' is data collected by the researcher extracted from first-hand sources, using fieldwork methods such as surveys, interviews, or experiments. Depending on the nature fieldwork performed, this primary data can be 'qualitative' or 'quantitative'. Secondary data is data assembled from studies, surveys, or experiments completed by previous academics. Secondary

data obtained throughout the literature review process will further bolster the researchers attained primary data and generate further discussion.

3.2.1 Qualitative

Qualitative research is 'subjective' in nature; meaning it is susceptible to opinions true to the modern-day conditions where there isn't any universal truth. It puts emphasises meanings and experiences, as such, this research can come in two forms, 'explanatory' and 'attitudinal'. Exploratory research is used when a limited amount of knowledge is understood around a topic. The purpose of this research intends merely to:

"Explore the research questions and not intend to offer final and conclusive solutions to existing problems. This type of research is usually conducted to study a problem that has not been clearly defined yet" (Saunders, 2012).

3.2.2 Quantitative

In contrast, quantitative research is 'objective'; not influenced by personal feelings or opinions to represent facts. Such data can be measured and represented as numbers, allowing statistical analysis procedures to ensue. These statistics can therefore be further analysed in allusion to the pre-existing hypothesis to determine whether the theories still hold true. Moreover, it can be deduced that *"Quantitative data is not abstract; it is hard and reliable measurements of tangible, countable sensate features of the world"* (Atkinson, 1995). Key differences between qualitative and quantitative datasets is summarised on Table 2.

Table 2: Main differences between qualitative and quantitative research (Bryman, 1998).		
Features	Quantitative	Qualitative
Role	Fact-finding based on evidence or records.	Attitude measurement based on opinions, views and perceptions.
Relationship between researcher and subject	Distant.	Close.
Scope of findings	Nomothetic.	Idiographic.
Relationship between theory, concepts and research	Testing/confirmation.	Emergent/development.
Nature of data	Hard and reliable.	Rich and deep.

3.3 Fieldwork Research

Fieldwork entails the method of the data collection stage of a research project; how researchers go about collecting data; or more narrowly, data collection in a social setting that tries to reflect the research question.

3.3.1 Types of Qualitative Fieldwork

The most popular qualitative data collection method is in-depth interviewing. Each interview must be transcribed and 'coded'; which is a process of finding *"how you define what the data is about"* (Payne, 2011). The process identifies key beliefs within the passages text, identifying concepts to finding relations between them. This data is directly transferrable in resolving objective one of this research; *"To recognize the attitudes of construction professionals towards the retrofit on MLWS's as a flood remediation technology and to interpret how their expertise diverge from construction undergraduates"*. Interviews can be approached in three main formats, structured, semi-structured and unstructured, a summation of each is observed in Table 3.

Table 3: Features of interviews formats (Winstanley, 2018).		
Structured	Semi-structured	Unstructured
Uses direct and specific questions only.	Some key questions planned, with allowance for other issues to be raised.	Free-flowing discussion; no fixed agenda.
Uses direct and specific questions only.	Indicative order of questions, but okay to depart from the order.	No specific order for questions.
The focus on how many people make the same points rather than individual views.	Supplementary questions are offered to collate people's different viewpoints, but all are expected to answer the main questions.	The interviewer is seeking depth of response and follows the interests of the interviewee.
Must follow fixed schedule.	Can leave out some questions as appropriate.	Difficult to replicate as follows interests of interviewee and these will differ from person to person.
Rather rigid style.	Relaxed style.	Conversational.

3.3.2 Types of Quantitative Fieldwork

The principle approaches to quantitative fieldwork include the formulation of questionnaires and the performance of laboratory studies. The application of this survey will provide statistical arguments for the resolution of objectives two and three. *Table 4* holistically contrasts the pivotal characteristics between interview and questionnaire fieldwork practices.

Table 4: Comparison between interview and questionnaire fieldwork techniques		
Features	Interviews	Questionnaire
Identification of respondents	Known.	Unknown.
Interaction between interviewer and respondent	Close.	Distant.
Time involving the researcher	Long.	Short.
Cost	High.	Low.
Sample size	Small.	Large.
Quality of information	Detailed and concise.	Rich.
Skill and experience	The interviewer needs to have interpersonal skills necessary to probe.	No skill required.
Control of the process	High.	Low.
Flexibility	Allows flexibility in answers and in clarification of questions.	Rigid.
Analysis of results	Difficult and becomes complicated.	Easy to analyse.
Interview bias	The flexibility of interviews sometimes allows bias.	If the sample appropriately there should be no bias.

3.4 Sampling

In research, the term 'sample' refers to a subset of elements drawn from a larger population. Once a fieldwork technique has been selected, careful thought must be given to the characteristics of the respondents. The researcher must ensure that the characteristics of the sample act as

representative to its population. There were many forms of sampling available to the researcher, some of these designs are listed below:

- Non-random purposive sampling.
- Non-random accidental sampling.
- Simple random sampling.
- Stratified random sampling.
- Systematic random sampling.

3.5 Outline Methodology

The variation in characteristics of the research objectives spearheaded the necessity to adopt a variation of investigation techniques, these were: quantitative personal interviews (*method 1*) and structured qualitative attitudinal questionnaires (*method 2*). The benefit of this approach allows for the cooperation of data sets to 'triangulate'; boosting the validity of each conclusion.

"Triangulation involves using more than one method to collect data on the same topic. This is a way of assuring the validity of research by a variety of methods to collect data on the same topic, which involves different types of samples as well as methods of data collection. However, the purpose of triangulation is not necessarily to cross-validate data but rather to capture different dimensions of the same phenomenon" (Healy, 2014).

With the intention of this research to determine the scientific and psychosomatic paradigms of MLWS benefits and the entrenched objections to the technology being a flood remediation mechanism.

3.5.1 Method 1: Personal Interviews

To begin this fieldwork, interviews were conducted to eliminate any ambiguity concerning the difference in attitudes between construction professionals and construction undergraduates towards the retrofit on MLWS's as a flood remediation technology. Furthermore, to delve deeper into the benefits, disadvantages and challenges they forecast in the retrofit of such systems. The interview itself comprised of 10 questions; probes were also introduced into the dialogue by the interviewer:

"Probing involves the use of specific words or other interviewing techniques by an interviewer to clarify or to seek elaboration of a person's response to a survey question" (Roe, 2011).

The script of the interviews conducted can be found on *Appendix A.1*. The formulation of a script intended to minimize any potential impact of the interviewers' behaviour on respondents' answers and the resulting data. The design of the interviews had been carefully thought out, where finally a formulaic semi-structured approach was opted for. Fully operationalized to suit the end user's needs, key questions were planned through a relaxed delivery style, with allowance for other issues to be raised by both the interviewer and respondent. This approach set out an indicative order of questions, with flexibility to depart from the order. The provision of only 10 questions has been assessed abundant in order to investigate key areas within the research.

A firm sample set of 10 interview respondents was targeted by the researcher, however regrettably, due to the COVID-19 pandemic, only a sample of 5 was attained. As for the sample itself, the respondents to this fieldwork were practicing Construction Professionals (CP'S) primarily affiliated to Kier Construction LTD, however, personnel under direct employment of Neath Port Talbot County Council and Swansea University were also interviewed in connection to the MLWS

at Swansea Universities IMPACT building. Contained by *Table 5* is a description of the interview respondents and the justification for their presence within this study.

Table 5: Interview fieldwork respondents.				
Respondent	Employer	Profession	Experience	Justification
1	Kier Group plc	Senior Project Manager	20+ years	1. Previous MLWS experience 2. Design expertise 3. Cost understanding 4. Client-side experience 5. Contract experience
2	Kier Group plc	Senior Design Manager	10+ years	1. Previous MLWS experience 2. Design expertise 3. Cost understanding 4. Contract experience 5. Planning expertise 6. Post-facility management
3	Neath Port Talbot County Council	Senior Quantity Surveyor	5+ years	1. Previous MLWS experience 2. Cost understanding 3. Contract experience
4	Neath Port Talbot County Council	Biodiversity Officer	5+ years	1. Previous MLWS experience 2. Biodiversity expertise 3. Planning expertise
5	Swansea University	Biodiversity Officer	10+ years	1. Previous MLWS experience 2. Biodiversity expertise 3. Post-facility management 4. Client-side experience

Allotment for supplementary questions are offered within the semi-structured methodology to collate respondents' different viewpoints, such as a contingency question. A contingency question can be defined as:

"A question that is answered only if the respondent gives a particular response to a previous question. This avoids asking questions of people that do not apply to them" (Barrett, 2011).

Contingency questions were injected toward to all respondents who were able to answer Q1:

"What previous experience do you have in constructing MLWS/LR systems?"

The contingency question came in the form of:

"What was the total cost for the system?"

This added layer of data will assist the researcher in gauging the current cost of MLWS's, how they have fluctuated over time, and mindsets towards their pricing. The first interview sample was extracted on 7th August of 2020 and the final on the 30th March 2020. All interviews were undertaken in quiet 1-to-1 office environments, such as site offices of live construction sites (Sancta Maria Hospital, Swansea, UK) or at corporation headquarters (The Quays, Neath Port Talbot, UK). By keeping this format throughout each interview meant that no external factors such

as 3rd party input or environmental changes could influence and distort the data obtained. In addition, performing this survey in a safe and familiar environment for the respondent in turn inspired a more open and honest dialogue. From here, respondents verbatim were recorded and transcribed for analytical coding.

On average, each survey took 13 minutes 30 seconds to conduct; an indication of the comprehensive nature of each response. A thematic analysis of interviews was then inaugurated.

3.5.2 Method 2: Questionnaire

To quantify experimental interviews; a survey aimed at the same research demographic has been compiled to assemble statistics. The theoretical framework of this questionnaire will follow directly from the interview stage.

Questionnaire Design

Questionnaire design is the process of designing the format and questions in the survey instrument that will be used to collect data about a subject (*Holyk, 2011*). Firstly, it was essential that the questionnaire was “piloted” and passed ethical scrutiny to reduce the amount of measurement error, this took place within a 2-week period from 6th January to 20th January 2020. A pilot questionnaire *“is a strategy used to test the questionnaire using a smaller sample compared to the planned sample size to mitigate errors and ethical issues”* (*Thomas, 2011*). Pilot testing provided the researcher with answers to the following:

- Are all the questions unambiguously worded?
- Might some of them be sensitive, so that respondents may avoid them?
- Are some of the questions too tricky to interpret?
- Are the instructions clear so that respondents clearly recognize what is expected of them?

The questionnaire design found on *Appendix A.2* undertook to above scrutiny, reducing the cognitive burden of respondents, containing an intuitive and logical flow. Undertaking non-random purposive sampling upon the UK-based construction undergraduates and practicing professional's demographic is justified by all correspondents having the idiosyncrasy of being within the construction industry at a management or undergraduate level, where all contributors will have an underlying knowledge of MLWS's, detailed knowledge of structural forms and building physics associated with retrofit, sustainability, existing government framework, building standards and cost intricacies essential to fulfilling the research objectives.

There were three central consequential goals of this questionnaire, firstly: to help provide professional guidelines to design managers who are required to design and retrofit MLWS's. Therefore, to investigate this, questions circled around design issues, barriers within previous education and training courses and recognized benefits to the system. Secondly, the area around enforcing compulsory MLWS's on all new government funded projects and the proposition for government-backed incentives were probed. To investigate this, questions forwarded the following:

- *“Do you feel that the construction industry is doing enough to promote the implementation of MLWS's?”*
- *“Should there be a government-backed incentive to retrofit MLWS's?”*
- *“Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory MLWS's installed?”*

Thirdly, to triangulate the questionnaire data back to the interview and moreover objective one, in addressing the attitudinal variance between construction professionals and students. Questions 4, 7, 10 were repeated from the interview into the questionnaire, permitting expansion on

previously 'closed' questions. Questions are ascendingly numbered, clearly spaced, and visually distinct from one another. Additionally, prior to beginning the survey, the respondent is met with clear and concise instructions of how to complete each question.

Within the 10-question questionnaire can be found a combination of open-ended and closed-ended questions, in addition to opinion questions, a means of subjective measurement. These consist of text boxes, checklists, yes-no questions and Likert scales. The variation of question formats grants many benefits to both the researcher and respondents, this method looks to keep the respondent as enjoyably invested as possible whilst being as short as possible, but comprehensive enough to derive information needed without alienating the respondent. The questionnaire was published via the online application 'Survey Monkey' as well as in a physical format allowing data collection 'in the field' in a naturally occurring setting for the respondents, i.e. on live construction sites and company headquarters. By using Survey Monkey, the research was enabled to reach the sample demographic more widely, negating the need for travel and added expenditure.

This likewise meant that respondents could complete the survey at whatever time they pleased, bettering chances of completion. The requirement for additional physical questionnaires was enumerated by the researcher's connection with the respondents, often handing out the questionnaires before interviews. The target number of respondents of this questionnaire was 30, with the goal of achieving a wide-ranging mix of expertise and construction disciplinary backgrounds to add further dimension to the conclusions. The questionnaire took approximately 3 minutes to complete with a 100% completion rate. The questionnaire period was open from 19th February for 4 weeks until 19th March 2020, minimizing the influence of attitudinal change over time as a result of economic and political influences.

3.6 Problems and Limitations

To help unravel Objective 2 in, *"constructing a comparative table showing the difference in performance between retrofitting MLWS's and other flood remediation technologies. The development of a mathematical formula to predict how much pluvial rainwater and a retrofitted MLWS can take out of the local environment will help promote this"* the researcher anticipated performing laboratory growth and precipitation studies upon MLWS growing medium, however, the inability to access key apparatus required for testing due to the COVID-19 pandemic didn't permit this.

Interview

Problems associated with the conveyance of interviews included the availability of respondents, cost of travel and the COVID-19 pandemic. In addition, due to the open-ended nature of the script, specific open-ended errors were highlighted, involving: (a) missing answers; (b) incomplete responses; (c) misunderstood terminology. These challenges were ultimately overcome thorough strong communication and efficient scheduling. As aforementioned; the surveys took place over the course of 7 months which was unfavourable, exposing the data to industry and financial shifts. The researcher also pre-planned further interviews with living wall experts, however, the COVID-19 pandemic barred these taking place.

Questionnaire

Qualitatively, a major handicap was the researcher's inability to clarify questions to the respondent undertaking the online-format questionnaires, as well as assuming a high degree of prior knowledge and understanding of MLWS's, instigating confusion and inappropriately informed responses. Also, the researcher had little control over whom completed the online-format questionnaires, although aimed at the demographic, any individual had access to the survey as

no preauthorisation or screening of candidates took place. Denouncing the data susceptible to manipulation and malice sample breaches.

3.7 Research Road Map

In conclusion, reinforced in **Figure 10** is a research roadmap that was developed as a guide for professionally fulfilling the research project.

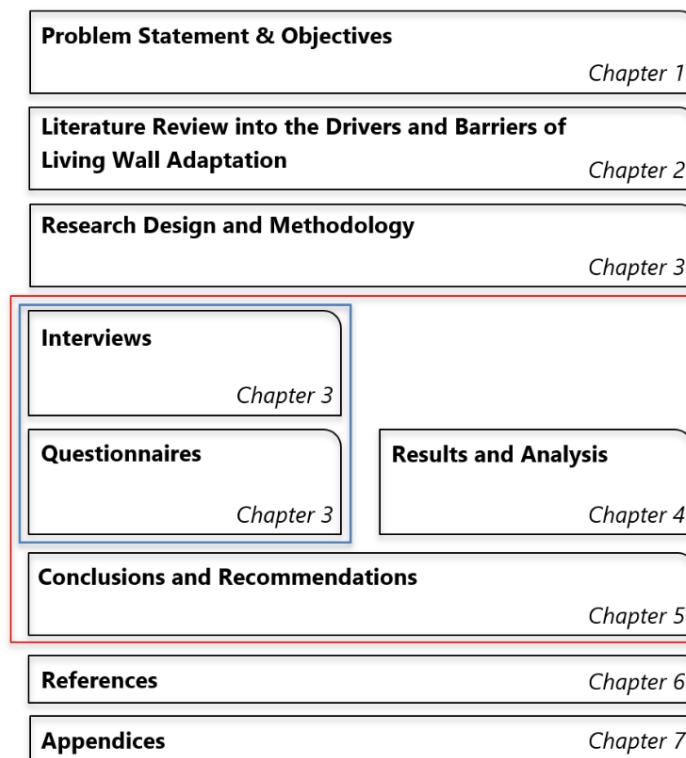


Figure 10: Researchers roadmap to fulfilling the research question (Author, 2020).

3.8 Plan of Work

A research programme summary of this investigation can be found on *Appendix A.3*.

Chapter 4 - Research Results and Analysis

Throughout this results and analysis chapter, the researcher will initiate an iterative process upon all data obtained: *“Iterative refers to a systematic, repetitive, and recursive process in qualitative data analysis. An iterative approach involves a sequence of tasks carried out in the same manner each time and executed multiple times”* (SAGE, 2017). This allows the researcher to continually refer to the literature review to compare historical data and principles to newly discovered evidence.

4.1 Statement of hypothesis testing

Hypothesis testing is an essential procedure in statistics. *“A hypothesis test evaluates two mutually exclusive statements about a population to determine which statement is best supported by the sample data. When the researcher states that a finding is statistically significant, it is thanks to the hypothesis test”* (SAGE 2019). Based on the theoretical argument and the literature review, the following hypotheses were formulated:

1. There is opportunity for retrofitting MLWS's however the framework and legislation necessary is currently unavailable or inadequate. Anticipating that retrofitting of MLWS's will be more economical than the alternative technologies currently being installed at the London Tideway Super Sewer.
2. There will be significant differentiation in opinion between construction professionals and construction students regarding MLWS's. Construction students being more familiar with the technology and its benefits.
3. It is expected that from the survey there will be a positive correlation between those with previous experience constructing MLWS's and those who believe that all future government-built buildings have compulsory MLWS's installed as they have been exposed first-hand to the benefits.

4.1.1 Interview Samples & Codes

Scrutinized at the outset are the qualitative findings. To initiate these results, primarily, the purpose of this fieldwork is to resolve objective one of the research; *“To recognize the attitudes of construction professionals towards the retrofit on MLWS's as a flood remediation technology and to interpret how their expertise diverge from construction undergraduates”*. The preferred method for data evaluation here is thematic analysis; assigning preliminary codes to the data to describe the content. In turn, searching for patterns and themes in the codes across the different interviews to ultimately define and represent findings in a user-friendly format.

“Coding verbatim responses is necessary with open-ended questions. While one of the main advantages of using an open-ended structure is getting specific, individual information, the lists of verbatim answers need to be organized to be useful for data analysis and reports. Developing numeric codes to accurately represent the verbatim responses is challenging and time intensive” (Ballou, 2011).

The complete interview transcripts and coding can be found on Appendix A.4.

4.2 Interview Results & Analysis

Data obtained in Q1 confirms that all five respondents have previously worked on projects encompassing a MLWS. Exhibited in Figure 11 is a stem and leaf visual aid, demonstrating the conformation that “Yes”, all respondents have prior experience in the edifice MLWS's.

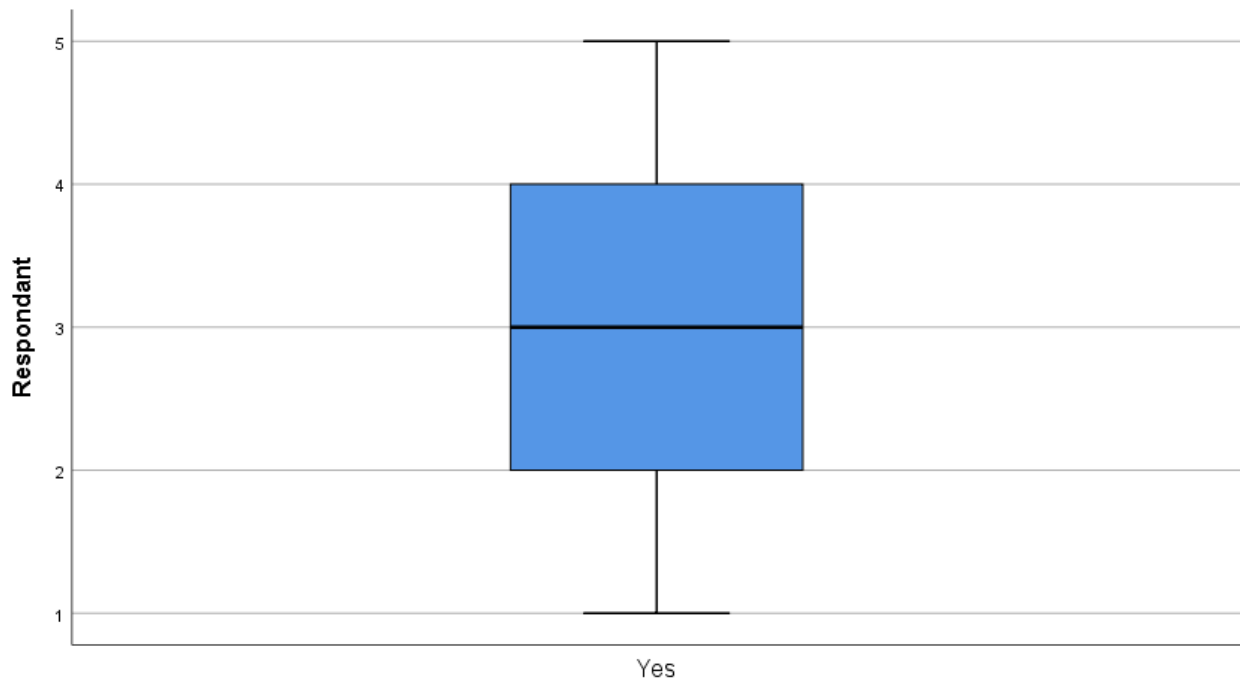


Figure 11: Question 1 stem and leaf graphic displaying respondents pre-existing MLWS experience.

Moving on to the second query of the interview, where in this subdivision respondents were probed to acknowledge the client's motives for MLWS implementation. This motive must firstly be understood by the researcher to secondly interoperate the industries current utilisation and operation for the system.

Question 2: What was the client's motivation for incorporating a living wall system?

Respondent 2

"On IMPACT it is probably about it being a focal point for the university because of where IMPACT sits at the entrance to the campus, they wanted a showpiece basically. So, they obviously get some sort of environmental benefit from it in terms of enhancing biodiversity, but they never really assessed that properly".

Respondent 2 states that the MLWS on their respective project was installed to serve a "focal point" to the entrance to the facility, whilst acknowledging that despite there are benefits of the system, these were not assessed appropriately. This outset is not mutually exclusive to respondent 2 however, Respondents 4 and 5 also named aesthetics as the central reason for installation. However, Respondent 1 asserts that on their separate project the system was installed due to drainage challenges, stating: *"It slowed how quickly the water was drained off"*.

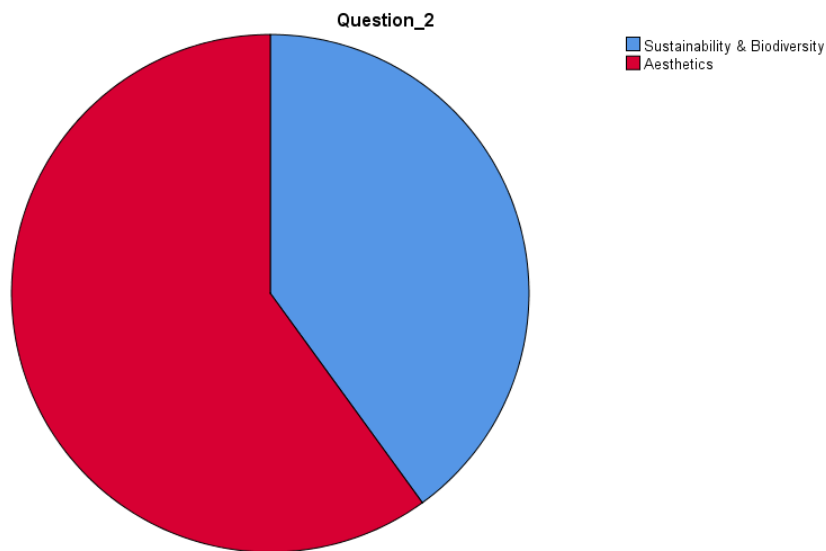


Figure 12: Pie chart exhibiting how client's aesthetic motives outweigh the sustainability and biodiversity gains.

Figure 12 illustrates that following coding procedures, a 3/5 majority places aesthetics as the main client motive on their respective projects. This emphasizes a stagnant concern facing adaptation, where clients view the system solely as aesthetic product rather than a flood repellent technology. However, the technology is being used to its full potential by some clients and contractors with the familiarity and expertise of its practicality.

Statement made by (Cooke, 2012) boosts the validity of this statistic by stating that the inclusion of MLWS's are *"a reflection upon the work of certain architects, designers and artists who display some kind of green aesthetic"*. Question 3 is an indicative test upon how competitive the MLWS market is, and if tendering and contracting procedures can be altered to improve adaptation. Additionally, this question will probe around the hostile area of total system cost.

Question 3: During the tendering stage for the living wall system, were there many responses and how competitive were they?

Respondent 1

"We would have gone out for 3 [tenders] because that is how the 2-stage tendering process works - you must get a minimum of 3 quotes. But there are not many companies in the UK that do it, so it does limit your opportunities. So, everyone has their own system, Biotecture and other companies will have their own system".

The above reference from Respondent 1 is a significant edict in comprehending the ease of tender. The respondent admits that there are not many companies offering the system, and those who do, provide difficulty to the client choosing a successful tender, since each contractor patents its own system. Agreeing with the statements made within the *UK government's sustainable development strategy (2005)* that concedes that the variability in design and lack of vendors delivers a stagnant tender process. This trend continues throughout the sample set, with all respondents conceding that this area is a significant stumbling block. Respondent 2 went as far as proclaiming that vendors can *"basically charge what they want"* whilst describing a lack of contractor competitiveness.

The question of post-completion maintenance can be a significant discrepancy within client uptake decision making. Therefore, the periodicity of maintenance and cost associated must be

accurately adjudged, as well as the consequences of contracting this service out above assigning it to the organisations facility management (FM) team.

Question 4: How was the system maintained post-completion?

Respondent 2

"We [Kier] agreed with the client that we would do 12 months, so we upgraded our maintenance to 12 months and that way £3,500. So that gives you a feel for how much it will cost the university post completion. It will cost the university about £3,500 a year to maintain that system. But that buys them that guarantee that it will always be green, providing all the nutrients it needs, pruning and replacement plants if anything dies".

£3,500 per annum for the maintenance of a MLWS's is typical and agrees with cost investigations undertaken by (Marc Ottelé, 2011). However, Respondent 2 goes further and impresses with the notion that *"If they [Client] start to put more living walls in, they'll have better contract terms because if you're maintaining two living walls or three living walls, they'll be better than if you are maintaining one"*. Therefore, indicating that within larger estates (i.e. the NHS estate) mass adaptation could consolidate considerable savings, conceivably making the system benefits more sensible to clients. Speaking about the practicality of maintenance, Respondent 5 states:

"If its tall [MLWS] you've got to get climbers going up to do the plants, so it's not as simple as, a plant has died and you have to replace it, it's quite an effort. Which goes back to the, you need space in front of the wall to get a MEWP so someone can safely access the higher plants".

This technicality leads the researcher to presume a likeness towards clients and maintenance contracts due to the works complexity and speciality. This agrees with (Mathew, 2014). who determines that this is the norm, however, denoting that for singular MLWS's significant costs can be avoided through in-house maintenance. How could we in the construction industry help promote MLWS's has generated a great deal of literature over the preceding ten years, the attitudes of experienced construction professionals will help gauge if these feelings differed from the literature owing to the attenuation of time or if any new suggestions occur.

Question 5: How could the construction industry help promote living wall systems better?

Respondent 3

"It is getting the architects and the planners on board to try and be putting this forward at the earliest stages. Cost is obviously an issue I think. Whether the industry can do more to promote it. The conclusions that I heard a lot of people coming to would be that they need to be pushed really by having sort of planning guidance that says you need to be putting them in place".

Citing lower cost and improved planning guidance as a precursor to improved MLWS promotion, Respondent 3, further states that MLWS contractors should be more vested in promoting the

system to clients, arguing clients are not familiarised with such technology yet. This qualitative fieldwork uncovered a recognizable trend, where just like Respondent 3, all other respondents highlighted the need for lower cost and improved planning guidance to enrich advancement. These and all further improvements mentioned by the respondents have been tallied to produce a detailed histogram, which can be found on *Figure 13*.

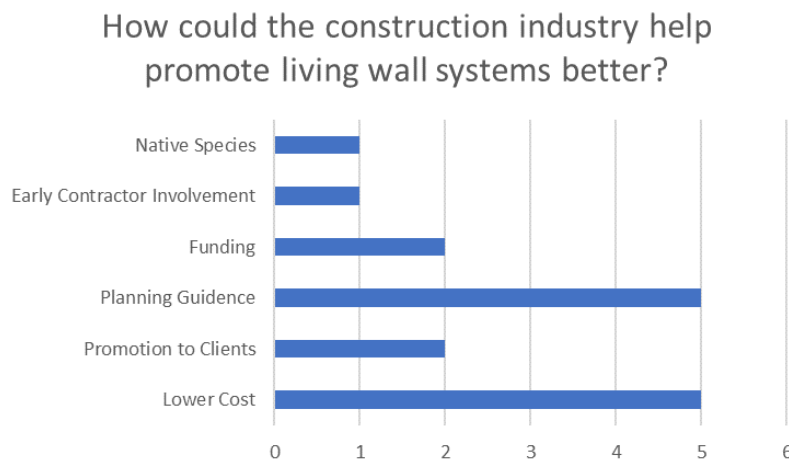


Figure 13: Tallied bar graph registering the improvements stated by the respondents.

Championing the efforts of (Katia Perini, 2011) this data plainly states that the cost of the systems is still too high and has been a common issue frustrating adaptation since the first UK MLWS company was established in 1984. From the viewpoint of planning, it is palpable that inadequate guidance exists and that during the design and construction phases a paucity of common standards was accessible. This evidence coincides with the

contemporary literature of (Gedge, 2008) who asserted that the events following the *Grenfell Tower Inquiry: Phase 1* (2020), existing MLWS guidance has been nullified.

Critical, are the viewpoints of experienced constructors toward MLWS's being interpreted as a cost-effective way of reducing rainwater run-off. Aforementioned literature by (Katja Hüve, 2011) reveals that MLWS's have the capability of eradicating up to 1L of rainwater per m²/day from the local environment, but given these benefits, how do they intermingle against performance/cost of other technologies professionals have encountered.

Question 6: Would you consider living wall systems as a cost-effective way of reducing rainwater run-off?

Respondent 2

"They [living roofs] will absorb a certain amount of the rainwater. And even if they are not absorbing it, they will attenuate it. So, they will slow it down from entering [sewer system]. But we do a lot of attenuation systems now where you put a massive tank underground that holds all the water and slowly reintroduces it into the drainage network. So rather than going in 25 or 30 litres a second into the sewer, we hold it back and then release it at maybe five litres a second. And that prevents the sewer from being overpowered".

The effects of this inquiry settle with all five respondents disregarding MLWS's as a cost-effective approach to reduce pluvial rainwater. When probed what technologies they would consider more cost-effective four respondents forwarded living roof systems and one attenuation tanks (see *Figure 14*).

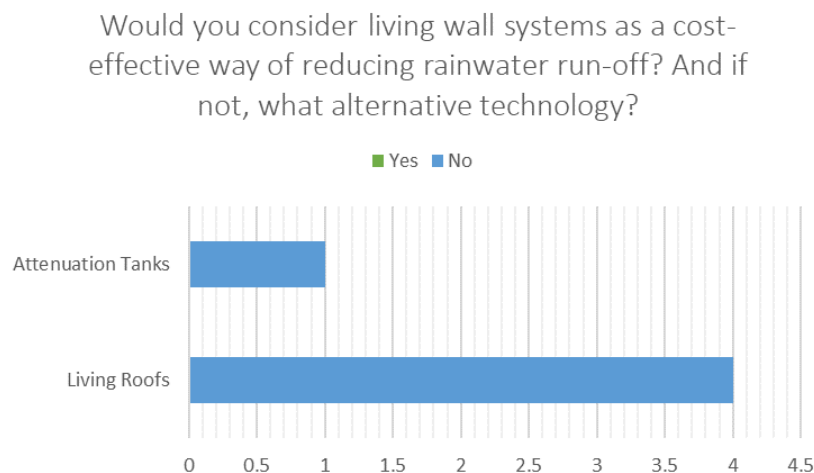


Figure 14: Graphic illustrating zero “Yes” responses to the research question and of the “No” responses, what alternative SuDS technology respondents see most cost effective.

Depicting significant findings in Chapter 2, it can be observed that these alternate technologies are successful in their application, but however, are also pricey. *Table 6* encompasses a comparative assessment of the cost difference between the mentioned SuDS. Absent are external factors such as the cost of maintenance, ease of maintenance and life cycle. The table highlights the evident comparative high

cost of MLWS’s but without comparison relating to rainwater performance, clients are unable to make informed decisions on the uptake. Moving deeper into the qualitative analysis, the researchers begins to protrude the idea of government-backed financial incentives to the respondents. Question 7 intends to make a business case for financial MLWS incentives to drive adaptation, this evidence can form the basis of a larger portfolio which the construction industry could present to UK parliament.

Table 6: Cost comparison of SuDS			
	100m ² MLWS	100m ² Living Roof	7,500L Attenuation Tank
Cost	£615/m ²	£100/m ²	£4,000

Question 7: Do you think government-backed financial incentives will help improve adaptation?

Respondent 2

“Yeah, I think most people are prepared to take on big buildings because your capital cost is often covered by someone else or you are not tending to be squeezing the pennies in quite the same way. However, I think that they are better off legislating. So, I think if they legislate, which is sort of the SAB regulations and stuff like that, I think that would have more of an impact, rather than saying we’re going to incentivize it or rather than saying “you will do it or we’re not going to be giving planning permission”.

Of the data set, the whole population agreed that government-backed incentives would drive adaptation of MLWS’s, however, differentiation amongst respondents varied regarding the appropriation of “what would be the point?”. Further to Respondent 2’s comment upon the prospect of legislating the system, Respondent 4 adds, *“Yes, but in my opinion, I don’t believe there’s that much of a need for them [MLWS’s]”*. In contrast, respondent 5 welcomes the prospect, expressing this as a “very important way to move forward”. This variability amongst respondents may perhaps be resultant of their contradictory stance on sustainability, or it might be true to their employment history where some respondents are used to working client-side, fixed upon reducing the project costs. Moreover, further to statements made by (Riley, 2017) represent a prospective

disparity in knowledge and expertise regarding MLWS's, this evidence will be triangulated in the following segment of this analysis.

The question of retrofit within this study is colossal. If it is found that MLWS's are a cost-effective way of reducing pluvial rainwater then the next issue contractors, planners and designers will examine is "how can we get this to market?". With a large chasm bereft of retrofitted case studies available, insight into what practices are implicated is weak within the literature. Therefore, this research delves deeper into the expertise of construction experts to assess and remediate any early issues they anticipate in the retrofit.

Question 8: What issues do you foresee for retrofitting such systems onto the UK's existing domestic housing stock?

Respondent 2

"Weight is a big one. I can see that something that would give much trouble to put that onto an existing building. They are quite heavy. I have slight concern about water penetrating through waterproof line. Anything that involves drilling into a system like that I'm always a little bit nervous about. I always worry slightly as well about introducing new cavities onto things because you can get mould and you can get damp and stuff forming".

Focusing on structural analysis of implementation, all respondents listed weight as an overriding issue halting retrofit. Respondent 3 extends beyond Respondents 2's comments by expressing *"There would have enough space to make it"*, alluding to the space need for plant to implement the system. An overriding census toward a lack of enthusiasm of the system is evident, Respondent 4 adding that holistically *"I do not think it'd be viable"*. To advance this imperative study, all qualitative evidence has been coded for juxtaposition in Question 10 of the quantitative data set (see *Figure 1*). This graphic proves a directory of areas required for structural and scientific investigation to permit safe trailing of retrofitted MLWS's.

The concept of asset and facility management directs decisions made on property renovations, therefore, why should the installation of a MLWS be any different? Judgments are habitually made on a cost/benefit basis in consideration to the whole lifecycle cost. So, with disagreements within the literature of (Cosola, 2019) and (Farrell, 2016) as to if MLWS's enhance a property's value. As such, this uncertainty was presented to the dataset with the aim of identifying what they interpret as "improved value" and what key variables influence them.

Question 9: Do you think a living wall system improves the value of a property when considering its maintenance costs?

Respondent 5

"I am sure they would. These buildings are attractive. They are more energy efficient. But I think from an aesthetic point of view that they are going to be more desirable and therefore more valuable".

Respondent 5 anticipates that buildings incorporating MLWS's are more valuable due to their improved energy efficiency and aesthetic benefit. This view however is not shared by the dataset, Respondent 3 stating *"I don't think there's been enough research yet to determine whether or not that really does have a financial impact"*. To extend, Respondent 2 works the example of the 2010 solar panel pandemic when feed-in tariffs were first introduced, telling:

"It is like anything, isn't it? Depends on your buyer. It does not necessarily increase the value. If someone invested ten grand and put solar panels on the roof. You would think that would increase the value of the house or the desirability because you get free energy. But a lot of people are unfamiliar with it and put off".

However, Respondent 4 extinguished a monetary term to the word "value", instead asserting a biodiversity stance, declaring that *"It [MLWS's] pays off if people think about biodiversity and green, but it might not necessarily get the benefits unless you plant native species to begin with, which not many places do"*. The primary variable that influences the correlation between the independent variable (MLWS's) and dependent variable (cost) that appear both in the verbatim and literature is location; Respondent 5 highlighting that *"Its [value] might be different in places like London where property values are so high and putting these things on makes them very desirable, paying for itself quite easily. A city like Swansea is a little bit different"*. Concurring with (Altan, 2015), who expresses:

"The application of these green wall systems would be different when applied in other parts of the world and their benefits therefore may be different depending on the scale of the project".

To give a more definitive outlook, answers have again been coded and cross tabulated with questionnaire Question 5 to create *Figure 21* in the quantitative research segment. Coinciding with the prospect of government-backed financial incentives, question 10 questions the prospect of compulsory MLWS's installed on all future government-funded buildings. All respondents formerly stated that incentives would drive application; however, this matter seeks to discover if the respondents attitude remains supportive when floating the concept of mass application.

Question 10: Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory 'living wall' systems installed? (Where applicable)

Respondent 2

"No, because I do not like anything that's compulsory on a building because it drives you towards a architectural feature for one, but also it drives a certain maintenance and drives you to towards certain company. I do not know how many companies are in the UK to do these things, but if you knew you were one of five companies in the UK that did it, you would charge twice the cost".

Respondent 2 opposes the requirement for compulsory MLWS's, citing the insufficient total of contractors trading in the field, and resultantly the instability of cost competitiveness amongst companies, a common theme across all interview questions. Still, the remaining respondents' views remained residually unchanged, Respondent 3 counterarguing:

"No. I believe they should have a compulsory, which they were ready to, I believe, and that they have their targets there. They must have "X" amount of space, which is, yes, to enhance biodiversity as a legal requirement".

To strengthen this attitude, Respondent 5 suggests that:

“There should be very strong arguments for not having one. I mean, there may be situations where it is not appropriate. So maybe compulsory is too hard. But I think that yes. It would be great if the emphasis were upon the expectation that they would have to”.

This compassion is autonomously authentic to the founding literature, which in the context of the London case study expresses that:

“The development of a more positive policy framework for living walls will enable London to balance its forecast growth in population and development with the environmental challenges ahead, in order to deliver a compact, resilient and liveable city that sets a new agenda for cities worldwide” (GLA, 2008).

This statement concludes the qualitative analysis. The subsequent segment triangulates interview accounts with the literature review and quantitative questionnaire analysis.

4.3 Questionnaire Results & Analysis

The results and analysis of the questionnaire are presented graphically and ascendingly, with the researcher citing literature review and qualitative findings to clarify the significance of the results. SPSS has been put into effect to firstly collate all questionnaire data and secondly, to induce statistical calculations upon the data, before representing them in graphical structure. All inputted SPSS data can be retrieved on Appendix A.5 and evidence of all completed questionnaires can be found on Appendix A.6.

Q1: What is your occupation? (e.g. Project Manager, Quantity Surveyor, Contracts Manager, Ecologist, Construction/Engineering Student, etc.)

Of the 30 respondents, the majority (70%) are construction professionals (CP). This means that going into the analysis, the statistical weighing of construction students (CS) will be slightly higher (*Figure 15*), to facilitate a fair comparison of both samples

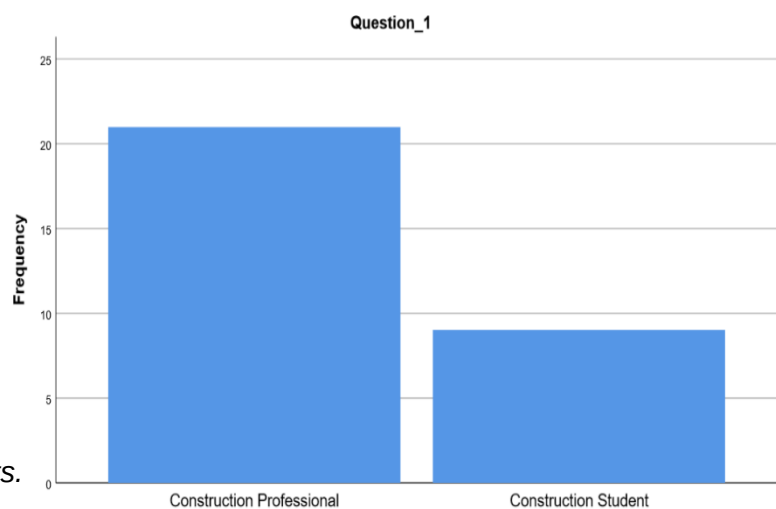


Figure 15: Bar chart illustrating the 21 CP and 9 CS respondents.

Q2: Have you previously worked on a project concerning a Modular Living Wall System (MLWS)?

Question 2 is important to recognize how judgments vary between those with experience working MLWS's vary between the rest of the sample set. Naturally, CS's will not have practical experience in this area yet, and so must be disregarded for this analysis. So, of the 21-strong CP sample set, 7 individuals had prior experience working with MLWS's leaving 14 without (*Figure 16*). This reflects the proclamation made by (*Sampson, 2018*) of a lack of experience and resultant lack of CP's gaining the knowledge and expertise. There are many external factors that may provide reason for this low number, however. Firstly, participants period within the industry has not been

measured, therefore, those with a greater number of years under their belt are statistically more likely to have prior experience. This statistic is still useful however, as it supports claims of client uptake amongst previous scholars.

Question_2 (Construction Professionals ONLY)

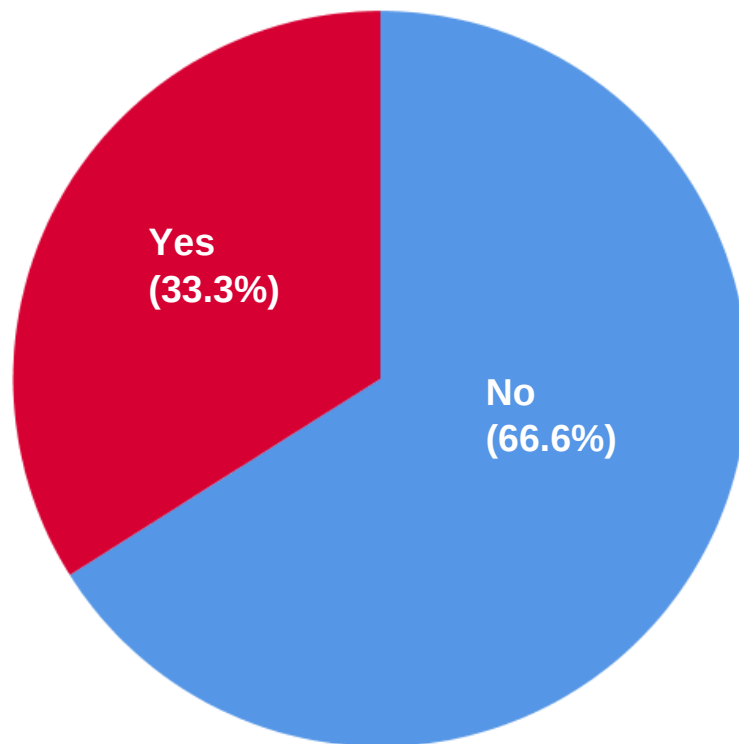


Figure 16: Pie chart illustrating pervious MLWS experience amongst the CP dataset.

Q3: Have you encountered MLWS's at any point during your time in education?

Statistics accumulated within Question 3 are immensely important, indicating that the basis to the gap in knowledge into MLWS begins at an educational level. The Yes-No nominal data supplied from CP's and CS's are presented independently in *Figures 17* and *18*, where "No" appears to be the overriding statistic in both.

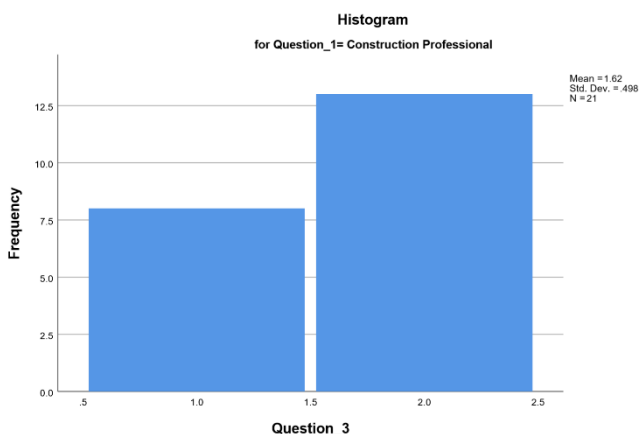


Figure 17: Histogram comparing Yes-No responses amongst the CP sample.

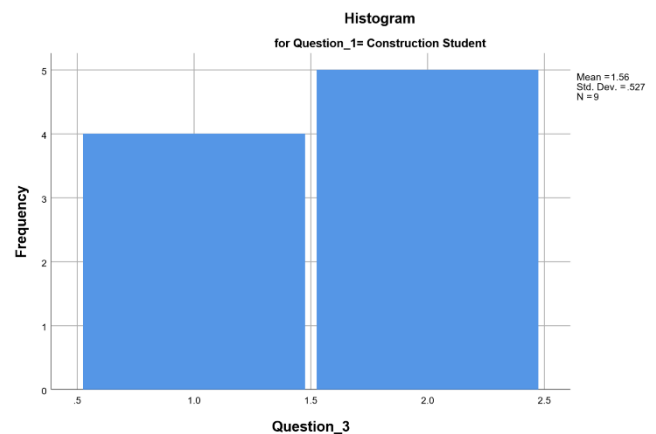
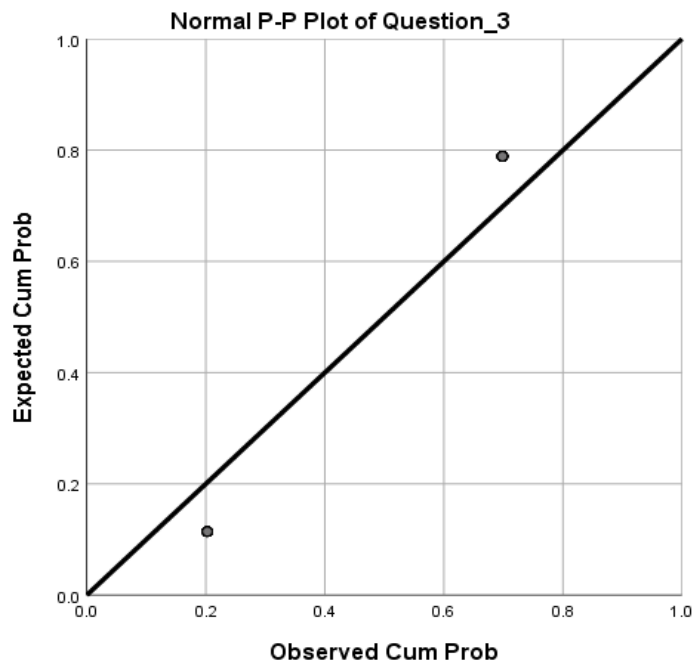


Figure 18: Histogram comparing Yes-No responses amongst the CS sample.

When comparing both statistics, the standard deviation values of *Figure 16* (0.496) and *Figure 17* (0.527) are statistically significant, where no difference between the tendencies exist. To rephrase, both statistics follow the same trend where generally respondents have not encountered MLWS's within prior education, supporting the claim of (*Dabaieh, 2017*). The sum of both sample sets favours the 'No' alternative 18 to 12 or in a 3:2 ratio.



Graphic 19 illustrates a P-P graph that represents the cumulative probability of the "No" option increasing throughout a larger sample population.

"P-P plot (probability–probability plot or percent–percent plot or P value plot) is a probability plot for assessing how closely two data sets agree, which plots the two cumulative distribution functions against each other. P-P plots are vastly used to evaluate the skewness of a distribution." (SAGE, 2020).

Figure 19: Question 3 P-P plot.

The graph builds on the claim of (*Altomonte, 2012*) and implies that this gap in knowledge will continue to grow without imminent action taken to "bend the curve" whilst stating;

"Advances in curriculum development must seek to promote this integration more effectively, and, in so doing, facilitate knowledge transfer between both the creative and the scientific disciplines that are core to a sustainable architecture and urban design process".

A conflict within the hypothesis has been dealt in that statistically, more CS's have not learnt about MLWS's during education than the assumed, more mature sample of CP's. Disagreeing with the statement of (*Hoffman, 2009*) in that the surgency of green technology over the last 10 years has developed more sustainably minded construction professionals.

Q4: What issues would you associate with MLWS's?

The objective of this inquiry was to locate the apparent overriding issues associated with MLWS's. From here, comparing them to the paramount issues featured within the literature review and described within interviews with professionals having prior experience in their construction. Obtaining the largest share of elects are both affordability and maintenance & upkeep as highlighted on the funnel graph on *Figure 20*. This evidence is again constant with the works of (*Perini, 2011*) and (*Borman, 2020*) respectively whom perceive the same issues as paramount.

To triangulate this data and tie up any loose ends, all interview respondents highlighted both liabilities as the principle snags to adaptation, in response to the same probe Respondent 1 ousted *"They [MLWS's] are scarce yeah, I think a lot of it is client driven, so I think it's high end. It comes at a cost, so it depends on budgets"*.

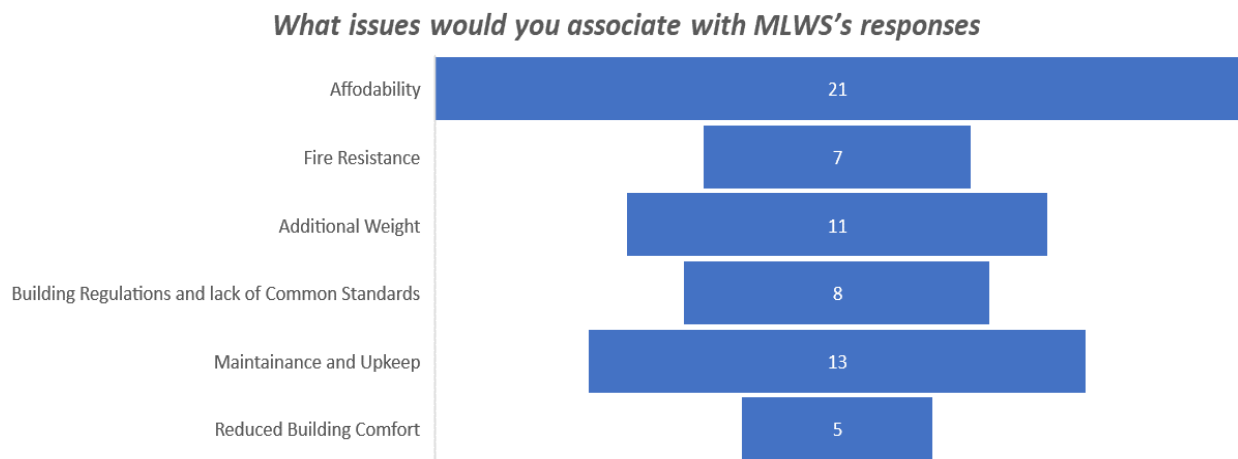


Figure 20: Funnel graph displaying cumulative qualitative and quantitative responses to issues associated with MLWS's.

This trend is pooled with the qualitative data, all respondents highlighted cost parameters as an adaptation restriction, respondent 2 acknowledging that *"certainly, there is an expense"* and whilst alluding to MLWS's maintenance and upkeep, the respondent states: *"the idea of putting it in is brilliant and everyone loves it. But not the idea of paying for it forever"*.

Discordant with the literature composed by (Riley, 2017), 88% of the respondents believe that Building Regulation compliance is not an issue limiting the retrofit of MLWS's. The prospect of reduced building comfort has been considered least cumbersome by the sample set, sharing merely 8% of the tally, research conducted by (Gunawardena, 2019) contests this factor by affirming *"some aspects can cause challenges to human comfort and health. These include CO₂ emissions from plant respiration, humidity, and discharge of allergens, and toxins"*.

Q5: Do you agree that MLWS's improves the value of a property?

The findings for question five are conclusive despite the presence of a "dead vote" (Not Sure) preference. Respondents in disagreement to the question statement amasses to 6, whereas those tallied in agreement were 13; more than double. 11 Abstaining from casting an opinion (see Figure 21).

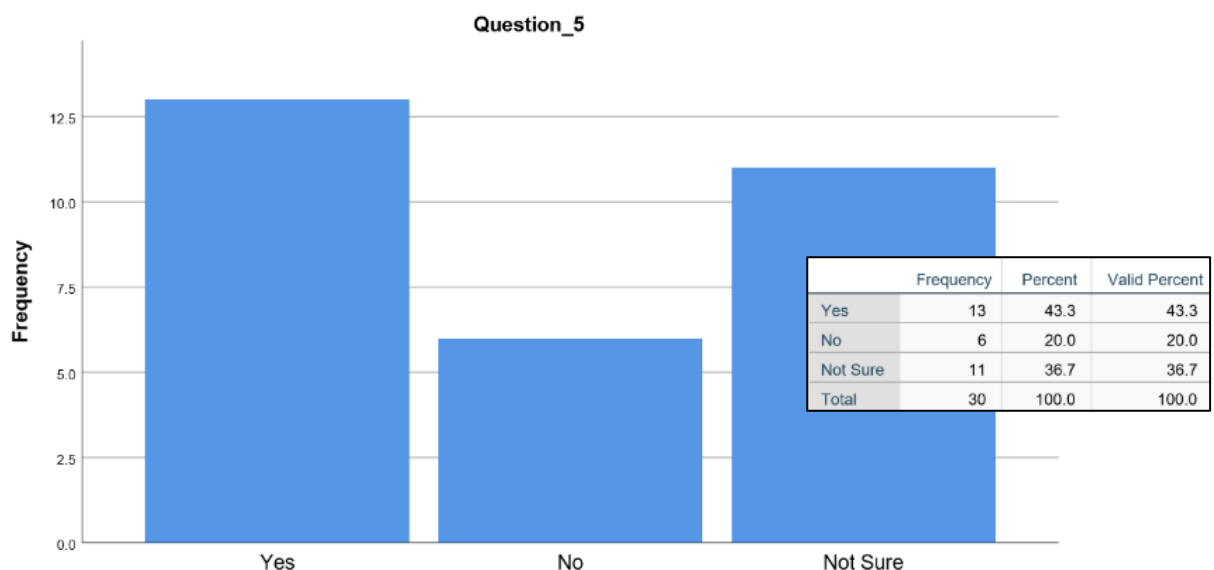


Figure 21: Building value increase attitudinal histogram and data.

Outcomes to Question 5 are in total disagreement to the qualitative findings, where dialogue from the CP's with prior MLWS experience largely cited the maintenance & upkeep costs of the system the main refute to the buildings sustained value, Respondent 2 sustaining that *"it'll cost the university [client] about £3,500 a year to maintain the system"*. However, little literature exists upon the true answer to this question, as there is no "one size fits all" solution to assessing value enhancement.

Q6: Do you feel that the construction industry is doing enough to promote the implementation of MLWS's?

Pivotal to satisfying Objective 3, and interlinked with Q7, is the samples insouciance toward the concurrent promotion of the MLWS, and further to these results, is there a requirement for government backed incentives. Overwhelmingly, 86.7% (see Figure 22) of the sample indicate that as of today, the UK construction industry is doing enough to promote the implementation of MLWS's. Of the 13.3% sample population who suggest otherwise, three are CP's and one CS, formulating no immediate correlation between those who answered yes and their current occupation.

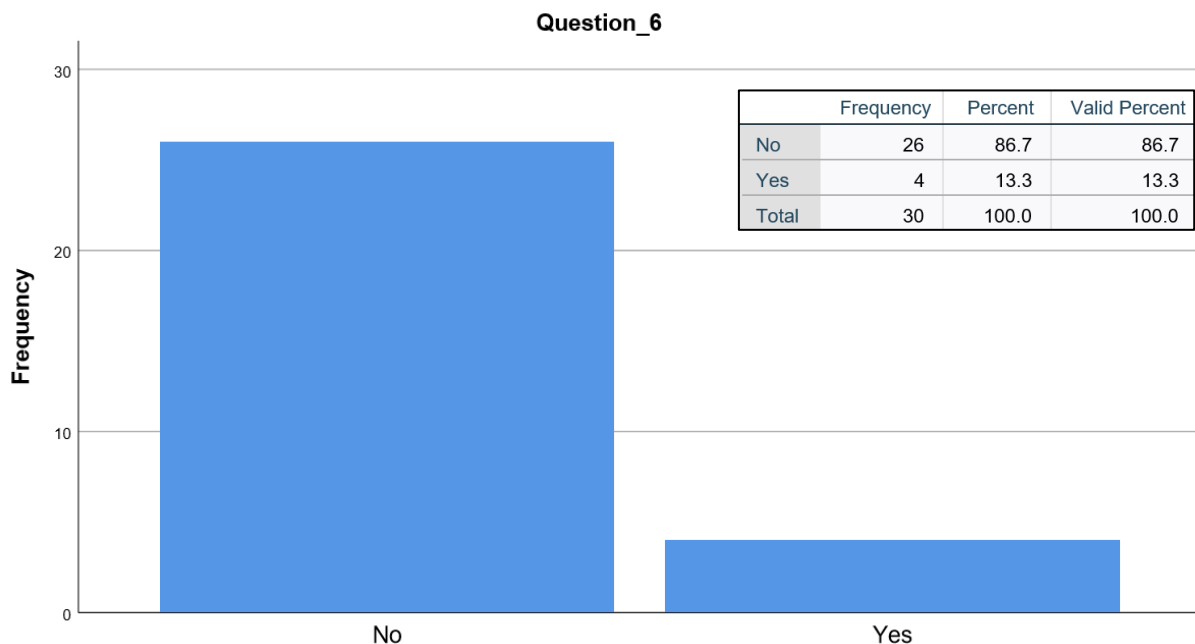


Figure 22: *Is the construction industry doing enough to promote MLWS respondent data.*

In triangulation, interviewees aloud suggested that the "industry is simply not doing enough" and additional planning guidance and lower system cost to stimulate adaptation. The literature review upholds this data, with work recognized by (Kennedy, 2019) stating *"It is suggested to increase the awareness of using vertical gardens among designers governments should subsidize greenery systems, and issue new legislation to encourage developers to do so"*.

Q7: Should there be a government-backed incentive to retrofit MLWS's?

Important to Objective 3, this data has been devised to make a case for government-backed incentives. Without the backing from CP's and CS's the argument has no impetus. The data represented in Figure 23 illustrates a steady rise and fall in respondents, "Agree" achieving the highest intensity of votes (11) and "Strongly Disagree" achieving zero elects. However, visually,

there is no clear attitudinal trend here, therefore other means of statistical analysis must be undertaken, such as Spearman's Rho.

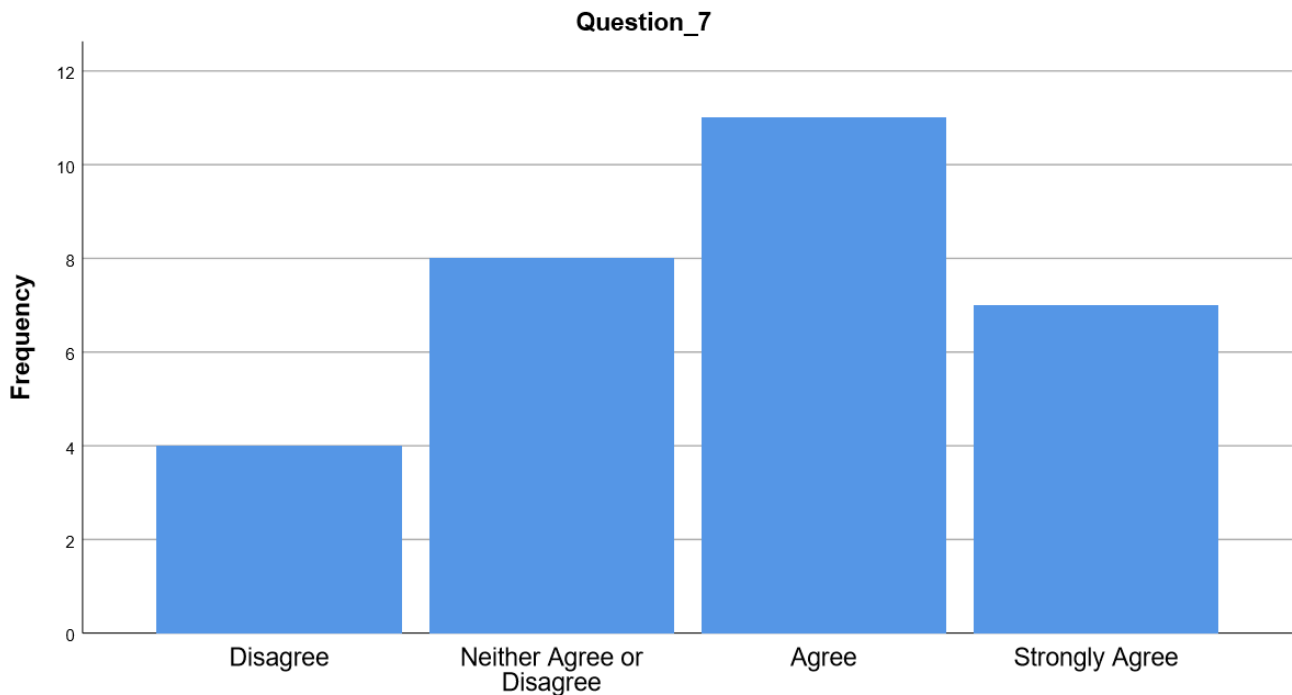


Figure 23: *Should there be a government-backed incentive histogram data.*

When treated as ordinal data, Likert results can be analysed using nonparametric tests. The application of Spearman's risk coefficient (ρ) definition of X will be manipulated to summarise the strength and direction (negative or positive) of a relationship between two variables within the questionnaire analysis "agree" and "disagree".

		Correlations	
		Question_1	Question_7
Spearman's rho	Question_1	Correlation Coefficient	1.000
		Sig. (2-tailed)	.
		N	30
	Question_7	Correlation Coefficient	.184
		Sig. (2-tailed)	.330
		N	30

Table 7: *SPSS Spearman's rho data.*

The formula for Spearman's Risk Coefficient is defined below:

Where:

N = Sample size

r_s = Correlation Coefficient

D = sum of difference between ranks

$$r_s = 1 - \frac{6 \sum D^2}{n(n^2 - 1)}$$

Highlighted on *Table 7*, the 0.184 correlation coefficient value obtained by the SPSS when cross-tabulated to the 2-tailed Spearman's Rho Table (see *Appendix A.7*) signifies a small to moderate correlation between the two datasets. Additionally, whilst using a 0.05 level of significance, the 2-

tailed value has been observed larger, therefore rejecting the hypothesis that no correlation exists between both CP and CS's and their attitudes toward whether there be a government-backed incentive to retrofit MLWS's. These statistics signify that the data obtained is true to the population, representing that it was collected fairly and representative of the population.

This supposition supports many periodicals promoting the uptake of such systems, founding literature by GLA stating that *the "Implementation of living roofs and walls is taking place in major cities throughout the world. For at least twelve of these cities, policy drivers and/or financial incentives are why living roofs and walls are being implemented so vigorously"*. The qualitative exploration, however, formulates resistance upon this belief, Respondent 2 casting doubt upon the usefulness of MLWS's, inferring: *"I don't think a wall can offer the benefit and therefore, I don't see that the government is going to put it"*.

Q8: Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory MLWS's installed?

The cluster bar chart graphic (Figure 24) typifies the contrasting opinions between the two samples. Where the CP data is very well rounded, visually including a central peak within the data responses, where on both sides a steady decline in responses is observed. Conversely, the CS data can be visually observed to favour agreement to the statement, where respondents abstained the "Strongly Disagree" field and gave the highest concentration of votes to "Agree". To further scrutinise what these results mean to the overall research question, and to survey how they compare to the literature review and qualitative data, chi-square analysis will be completed to ensure this data is statistically sound.

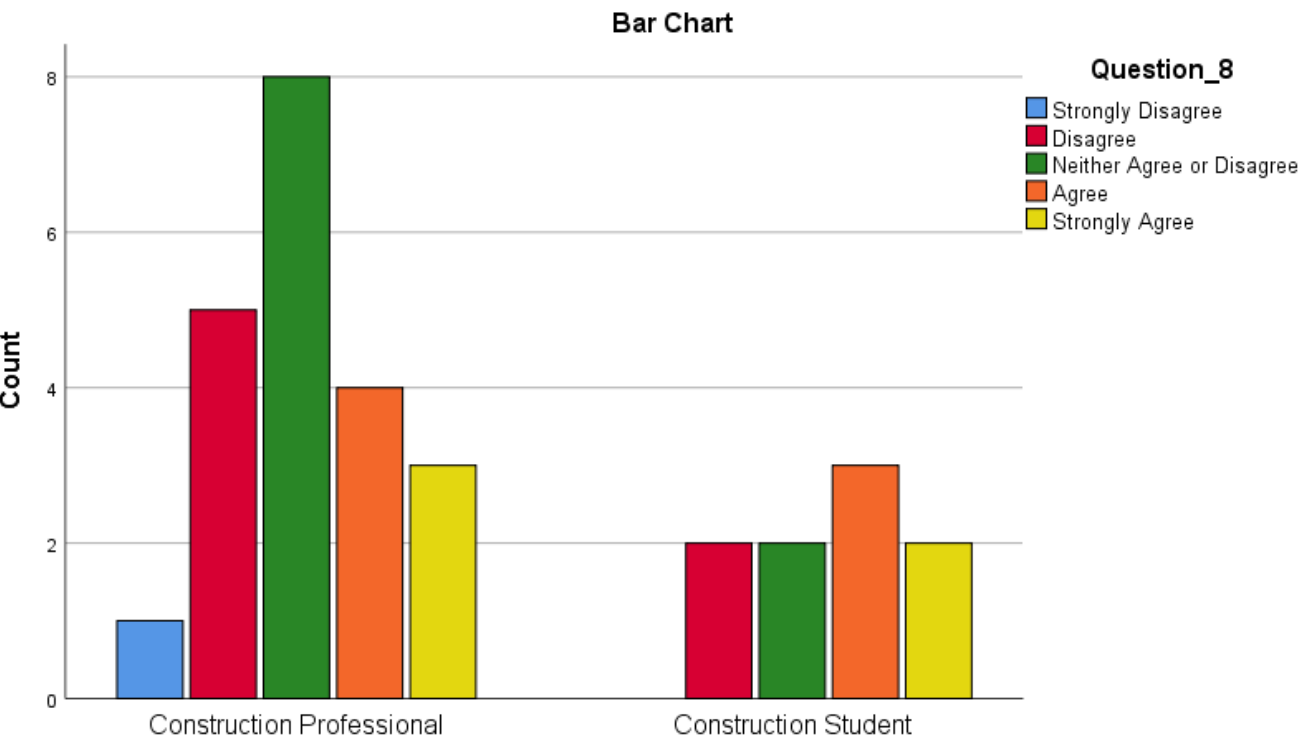


Figure 24: Attitudinal research into if all future government-funded buildings should have MLWS's installed respondent cluster bar chart data.

This time, data obtained from the Likert scales will be reduced to the nominal level by combining all agree and disagree responses into one of two corresponding categories (e.g. "accept" vs. "reject"), whilst voiding the "Neither

Agree or Disagree” dead votes. When this transformation occurs, a chi-square the statistical procedure will be applied. Benefits of adopting the Chi-Square test includes its robustness with respect to distribution of the data, its ease of computation and the detailed evidence that can be derived from the test.

Chi-Square Tests			
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	1.701 ^a	4	.791
Likelihood Ratio	1.977	4	.740
Linear-by-Linear Association	.868	1	.352
N of Valid Cases	30		

Table 8: SPSS Pearson Chi-Square data.

The formula for Chi-Square is defined below:

Where:

C (or Df) = Degrees of freedom

O = Observed value(s)

E = Expected value(s)

$$\chi_c^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

Formulated from SPSS data on *Table 8* is a resultant 0.791 significance value. Whilst testing at the 5% level of significance this figure is exceedingly higher than 0.05, meaning this result is not statistically significant, where there is not enough of a agree distribution to clarify a strong enough assumption between CP's and CS's and the research question and that the options are independent and not dependent on each other. Although, beneficial to the researcher, another small to moderate link exists between the respondents and the research question. This has been identified through cross tabulating the Chi-Square value of 1.701 to the Chi-Square table found on *Appendix A.8*.

This conjecture supports the results of the Spearman's results in Question 7, noting that in addition to arguing the stipulation for government-backed incentives, there is also a small to moderate link that government backed projects should also integrate the technology. Academia from the literature offers both supporting and scepticism to the impacts of this conclusion. While supporting documentation by (Gunnell, 2013) advocates the systems biodiversity benefits, conversely, to add doubt (Baumann, 2015) states that “It's [compulsory MLWS's] not necessary nowadays with alternative technologies available”. Through further triangulation, qualitative exploration, respondent 3 extrapolates support by saying in mention to government sustainability targets that “we must enhance biodiversity. We cannot just do nothing”.

Q9: What benefits do you believe MLWS's bring?

The objective of this inquiry was to ask respondents for their single most important benefit, expecting for an eminent trend to appear that's supports the hypothesis that MLWS's can assist the reduction of pluvial surface water, and sustain many other aspects within a buildings performance. Dissected further is how these perceptions compare between CP's and CS's before applying further quantification from the founding literature. Produced by SPSS, *Figure 25* operates another cluster bar graph, this time to contrast CP and CS attitudes for perceived system benefits.

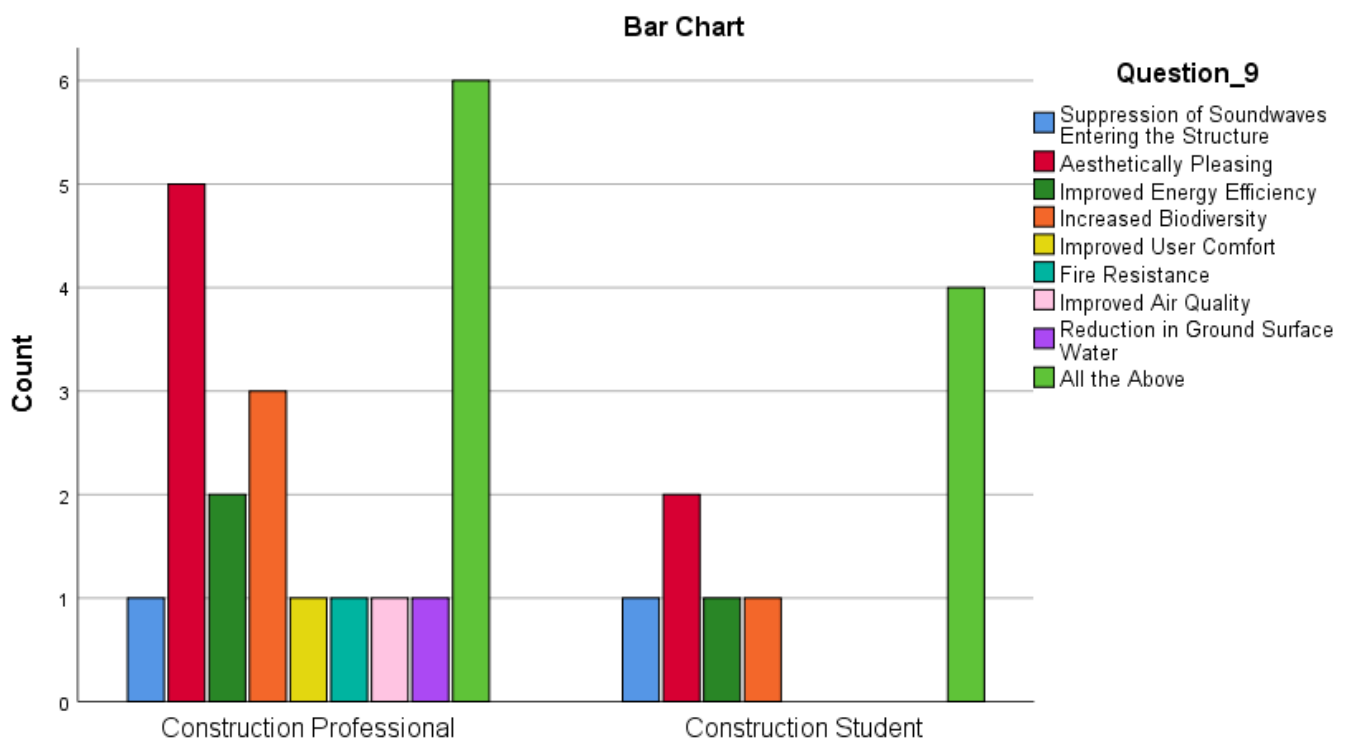


Figure 25: CP and CS recognized benefits cluster bar chart data.

Despite less representation of the CS demographic, many similarities between each dataset is observed. In both samples, the overriding inclination for respondents was the “All the Above” field, where respondents 10 respondents (or 33.3%) agreed with all the statements. Singularly, the preferred benefit was the “Aesthetically Pleasing” field, cumulatively achieving a 56.6% share of the vote. Strikingly, with the smallest representation, attaining 11 (or 36.6%) of the vote share is the “Reduction in Ground Surface water” fields. A damning conclusion from this investigation which identifies the attitudinal barrier against the ideology that MLWS’s can be used as a floor prevention mechanism, the basis of this investigation.

In contradiction, (Perini, 2013) presents a MLWS retrofit project in Genoa, Italy which illustrates the successful deployment of MLWS’s exclusively to eradicate rainwater from a dense urban area. Mentioning back to statistics accumulated within Question 3, it could be deduced that the basis of this oversee could be a direct result of the gap in MLWS knowledge imbedded at an educational level.

However, interview question 5; “*Would you consider MLWS’s a cost-effective way of reducing rainwater run-off?*” quantified the industries cynicism toward this benefit. Respondents 1 stating that “No. Roofs, maybe. But not wall systems”. However, in refute, Respondent 1 states “*I’m sure it would but by just how much, I’m not sure*”.

Q10: What issues do you foresee for retrofitting such systems onto the UK’s existing building stock?

The integration of an open-ended opinion question to conclude the quantitative fieldwork quantifies a 3-dimension backbone to interview Question 8, indistinguishable by the same title: “*What issues do you foresee for retrofitting such systems onto the UK’s existing domestic housing stock?*”. Responses have been coded (see Appendix A.9) and tallied where juxtaposition of both data sets can be seen below in Figure 26.

What issues do you foresee for retrofitting such systems onto the UK's existing building stock combined qualitative and quantitative responses

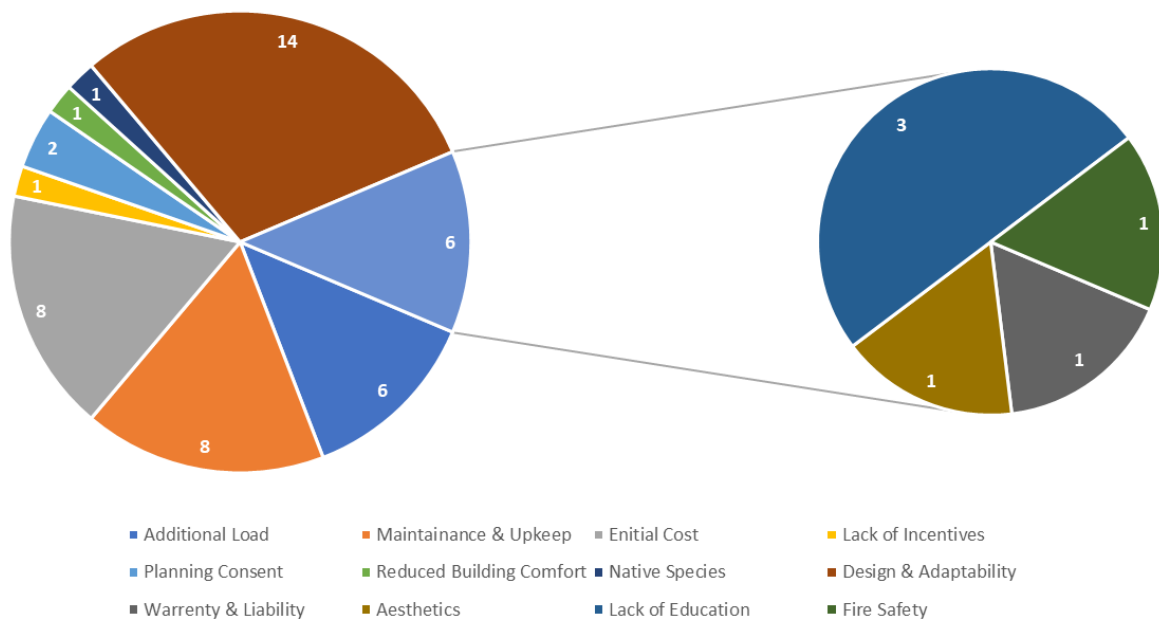


Figure 26: Combined interview and questionnaire responses to foreseen issues with retrofitting MLWS.

Again, in backing of Question 4: “What issues would you associate with MLWS’s?”, affordability and maintainance & upkeep control the way as central issues. Whilst design intricacies are deemed the single most popular issue, under the sub-codes lies issues with damp, wall breathability, drainage, floor levels and compatibility amongst traditional builds. However, the open-ended nature of this question seeks the discovery of new concerns. Contractually speaking, a respondent submits: “from a commercial & contractual perspective, further investigation into warranty & liability will need more in-depth consideration”. Literature upon this facet is extremely limited and should therefore be additionally examined in aggregation to the UK MLWS industry expressly.

In addition, for the first time in this investigation the question of building equilibrium has been exposed, where a respondent estimated “retrofit may also create issues with the existing equilibrium of buildings as certain areas are not designed to accommodate these systems”. However, this judgement is suppressed by the scholar (Wahba, 2018) of whom states:

“Green layers reduce the amount of energy needed to control the internal temperature of the building and reducing energy consumption. While providing interior temperature moderation, during warm months a green envelop increases evapotranspiration, thus cooling the surrounding air”.

The conclusion to this question emphasizes that issues perceived by CP’s and CS’s concerning MLWS’s run beyond just cost and maintainance. A trend of issues exists across educational, contractual, fire safety and civil engineering cohorts. It is evident that improved cooperation between these parties regarding MLWS’s may drive advancements in bringing this product to the UK retrofit market.

Chapter 5 - Conclusions and Recommendations

This chapter intends to conclude and dissect Chapter 4: Results and Analysis whilst remaining tightly tethered to the aims, objectives and hypothesis found in Chapter 1: Rationale for the Research.

5.1 Conclusions

The objectives of this research were threefold and have been concluded systematically below:

Objective 1: To recognize the attitudes of construction professionals towards the retrofit on MLWS's as a flood remediation technology and to interpret how their expertise diverge from construction undergraduates.

The researcher had difficulty observing any statistically significant findings, where no difference between the tendencies existed in key surveyed areas. In the critical area of education, *Figure 19* builds on the claim of (Altomonte, 2012) who implies that this gap in knowledge will continue to grow without imminent action taken to "bend the curve" whilst stating;

"Advances in curriculum development must seek to promote this integration more effectively, and, in so doing, facilitate knowledge transfer between both the creative and the scientific disciplines that are core to a sustainable architecture and urban design process".

A conflict within the hypothesis has been dealt in that statistically, more CS's have not learnt about MLWS's during education than the assumed, more mature sample of CP's. Disagreeing with the statement of (Hoffman, 2009) in that the surgency of green technology over the last 10 years has developed more sustainably minded construction professionals. Additionally, when interpreting attitudinal differences concerning incentivisation and compulsory MLWS's, CS's and CP's results were not statistically significant. The agree distribution was not compelling enough to clarify any assumption between CP's and CS's.

This conclusion nullifies the hypothesis that: *"There will be significant differentiation in opinion between construction professionals and construction students regarding MLWS's. Construction students being more familiar with the technology and its benefits".* Although the researcher's hypothesis was not met, it is adjudged that adequate evidence exists to successfully conclude this objective.

Objective 2: To provide professional guidelines to design managers who are required to design and retrofit MLWS's through constructing a comparative table showing the difference in performance between retrofitting MLWS's and other flood remediation technologies. The development of a mathematical formula to predict how much pluvial rainwater and a retrofitted MLWS can take out of the local environment will help promote this.

The proprietor of this research concludes the following guidelines toward the mass retrofit of MLWS's:

1. Consider preliminary and ongoing costs.
2. Anticipate a prolonged planning consent process.
3. Premeditatively engineer the additional load of the MLWS.
4. Plan for maintenance & upkeep difficulties.
5. Consider reduced building comfort.
6. Design out damp and promote wall breathability.
7. Consider fire safety.
8. Contractually evaluate MLWS warranty and liability.

Entailing additional exploration, the researcher has successfully begun to construct a one-size-fits-all formula, easily adaptable to any MLWS scenario with the change of individual values. This formula will prove a crucial tool to clients, designers, planners, and local authorities alike in evaluating a buildings financial adaptability to the retrofitted SUDS. Delineated below:

$$MLWSm^2 \times H_2O \text{ (Potential Eradicated)} = R1$$

$$Average \frac{\text{rainfall}}{\text{year}} - R1 = \text{Total benefit (m}^3\text{)}$$

A demonstration of this formula has been deployed to support the achievement of Objective 3.

Objective 3: To evaluate the cost of MLWS's per m^2 to the alternative technologies currently being installed at the London Tideway Super Sewer and to additionally critically appraise if imposing MLWS's compulsory on all new government funded projects would help lower the costs of the system, as well as making a case for government-backed incentives.

To further these guidelines, and to help remediate existing challenges and remove ambiguity confronting contractors and clients alike the author successfully accurately produced a comparative table illustrating the cost variance between MLWS's and sewer upgrades taking place at the LTSSP. The researcher applied existing CSO and cost data within the Borough of Kensington & Chelsea segment of the project to cross-tabulate with the mathematical formulas prepared.

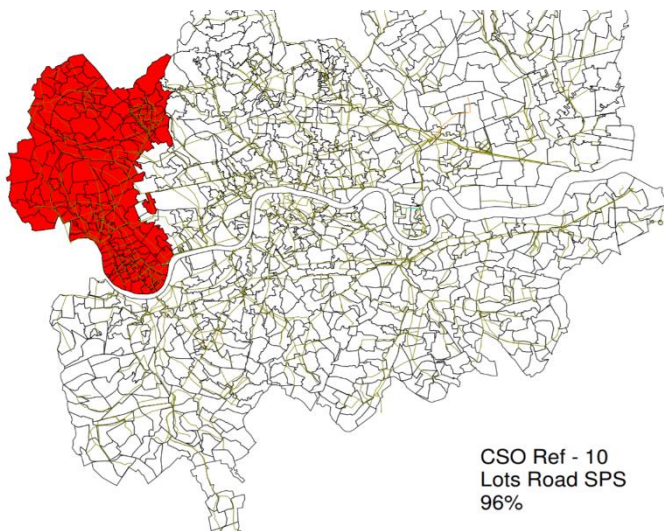


Figure 27: Kensington & Chelsea CSO (Thames Water, 2013).

Chapter 2 defined that 39 million tonnes of untreated waste water containing raw sewage enters the River Thames each year (DEFRA, 2015), further evidence estimates that the CSO's in the borough of Kensington & Chelsea, one of the worst hit areas of pluvial flooding (see Figure 27), amount to 3,946,650 tonnes a year (Feasibility Study Final Report, 2013), or 328.9 tonnes a month. In 2019, the annual precipitation in Kensington & Chelsea amassed to 754mm, encompassing a monthly average of 62.80mm (Met Office, 2020). Multiplied by the 12.12 km^2 area of the borough, this approximates that 761.1 tonnes of pluvial rainwater enters the sewage infrastructure every month.

Therefore, it can be deduced that with the total eradication of the 761.1 tonnes of pluvial rainwater from the sewage system, no overflows in this section will occur. However, realistically, this is never going to happen, still holistically, a significant percentage can be eliminated to prevent overflow. The researcher has devised the following formulae to measure the minimum percentage of AVG_{PR} that can be eradicated so achieve zero spill.

$$\begin{aligned} \text{AVG}_{\text{PR}} - \text{AVG}_{\text{CSO}} &= \text{MT}_{\text{PR}} (\%) \\ 761.1 - 328.9 &= 432.2 (56.8\%) \end{aligned}$$

Where:

AVG_{PR} = Tonnes of average monthly pluvial rainwater in the borough.

AVG_{CSO} = Tonnes of average monthly CSO's in the borough.

MT_{PR} = Monthly deduction of pluvial rainfall required for zero CSO spill.

To clarify these results, 56.8% is the minimum amount of pluvial rainfall requiring elimination prior to zero CSO spills in the Borough of Kensington & Chelsea. However, for an added buffer against climate change, freak weather events and for supplementary simplicity of further calculation the researcher will increase this value by 3.2% to 60%. The MT_{PR} of 432.2 tonnes now equates to 446 tonnes following the 3.2% increase. The subsequent stage in this calculation procedure necessitates the 446 tonnes of MT_{PR} to be converted to litres (L), this is to permit the calculation of the total m^2 of MLWS's required to achieve zero spill. The basic conversion of 1 tonne of water to litres is as follows:

$$1 \text{ U.K. long ton of water} = 1,016.05 \text{ litres of water (L)}$$

$$446 \text{ tonnes} = 453,157 \text{ litres}$$

The converted MT_{PR} value of 453,157L can now be integrated into the below calculation, where based on the literature (*Hüve, 2011*), MLWS's have the capability of eradicating up to 1L of rainwater per m^2/day from the local environment. The MT_{PR} value of 453,157L apportioned into 30 produces a DT_{PR} figure of 15,105.

$$\frac{\text{DT}_{\text{PR}}}{1\text{L}/\text{m}^2} = \text{Tm}^2 \quad , \quad \frac{15,105}{1\text{L}/\text{m}^2} = 15,105\text{m}^2$$

Where:

DT_{PR} = Daily deduction of pluvial rainfall required for zero CSO spill.

Tm^2 = Total m^2 of MLWS required.

This calculation concludes that 15,105 m^2 of MLWS is required to prevent CSO spill + 3.2% in the Borough of Kensington & Chelsea. The final part of this study aims to contrast the total cost of MLWS required vs the cost of the LTSSP. To calculate the cost of MWLS, the case study found on page 14 of Chapter 2 will be utilised, where the system implemented amounted costs of £615/ m^2 .

$$Tm^2 \times \text{Case Study } \text{£}/m^2 = TC$$

$$15,105 \times 615 = \text{£}9,289,575$$

Where:

Tm^2 = Total m^2 of MLWS required.

TC = Total cost.

Enough data has now been obtained by the researcher to create a comparative table, attempting to equate the most up to date cost of the LTSSP against the projected cost of large-scale MLWS implementation within Kensington & Chelsea (see Table 9).

Table 9: Kensington & Chelsea MLWS vs LTSSP cost comparison.		
MLWS	Description	Associated cost (£)
	15,105m ² of retrofitted MLWS across the borough.	£9,289,575
London Tideway Super Sewer Project (LTSSP) in the Kensington & Chelsea Borough.	A new foul sewer system is proposed in this area. With interceptors running from west to east to the destination of Beckton Treatment Works.	£73,862,000 (see Appendix A.10)
Maintenance and upkeep costs for BOTH schemes do not form part of this study		

The outcomes from this information-gathering unambiguously concludes that the mass-retrofit of MLWS as a cheaper alternative to the LTSSP upgrades in the Kensington & Chelsea Borough of London. Overturning attitudinal data gathered within Question 4 of the Quantitative fieldwork, where respondents targeted affordability as the biggest snag to adaptation, obtaining the highest concentration of votes (32%). To triangulate, further doubt has now been cast upon the declaration of all interview respondents who shared this viewshed, of which Respondent 3 exclaimed “£700 per square meter of an area of 116 metres squared, that it is a big ask”. This evidence is also contradictory to the pre-assessed prospect that MWLS’s were a non-cost effective alternative to dealing with pluvial localised flooding in London, stating: “*This option would require properties to be retrofitted which is more costly than the tunnel option at an estimated cost of at least £13 billion*” (DEFRA, 2015).

The researcher’s critical appraisal into if imposing MLWS’s compulsory on all new government funded projects would help lower the costs of the system ensued in the hope of formulating a business case for government-backed incentives. Succeeding an analytical census it was noted that in addition to respondents within the qualitative fieldwork arguing that the biggest stipulation to MLWS’s is the lack of government-backed incentives and associated elevated cost, that there is also a small to moderate link quantitatively that government backed projects should also integrate the technology. Academia from the literature offers both supporting and scepticism to the impacts of this conclusion. While supporting documentation by (Gunnell, 2013) advocates the systems biodiversity benefits, conversely, to add doubt (Baumann, 2015) states that “*It’s [compulsory MLWS’s] not necessary nowadays with alternative technologies available*”. Through further triangulation, qualitative exploration, respondent 3 extrapolates support by saying in mention to government sustainability targets that “*we must enhance biodiversity. We cannot just do nothing*”.

However, definitive data to question whether these practicalities would drive down system cost were unattainable, however, attitudinal qualitative data shows a conflict amongst CP's where Respondent 2 states in references similarities between prospective MLWS incentives and past solar PV incentives, stating: *"there will be people jumping on the bandwagon to make money"* where conversely Respondent 3 expresses *"I don't think there's been enough research yet to determine whether or not that really does have a financial impact"*. However, further to these findings the researcher defines that prospectively the associated high cost of MLWS's can be reduced if both short-term investment and long-term maintenance are tethered, optimized, and subsidized. Furthermore, ROI's will increase once MLWS's tangible benefits such as energy savings are quantified.

5.1.1 Achievement of Research Aim

Further to the research aim *"to evaluate whether the retrofitting of living wall systems on existing building stock is a cost-effective way to prevent pluvial localized flooding in UK cities"* a definitive conclusion has been released within this research. It as been proven through extensive literature research that the system has the capacity to prevent localized pluvial flooding, and through further triangulation, mathematical calculations have determined a high degree of cost-effectiveness against the LTSSP case study. Effectively offering professional guidelines to constructors through the creation of mathematical formulae and cost comparison tabulated data.

5.2 Recommendations

To succeeding academics furthering this investigation, the researcher recommends a new statistical approach to investigate deeper the attitudinal disparities between CP's and CS's concerning MLWS's and SuDS more widely. This, in addition to sampling a greater and equal CP and CS population, where additional parameters are set upon the sample (e.g. each CP has 5+ years' experience and each CS is in their final year of their studies). This will ensue a greater accuracy of results. Furthermore, there is a capacity for modifications to be made to the theoretical framework applied to analyse the need for incentivisation and compulsory MLWS's on government projects. These alterations include the cross-referencing of solar PV uptake data and resultant cost degeneration which could prove comparatively similar to MLWS's ought the proposed legislation be put in place.

5.3 Limitations

Research deficiencies within this research are primarily owing to the cancellation of pre-planned interviews with living wall experts where the COVID-19 pandemic barred these taking place. Additionally, the researcher anticipated to perform laboratory growth and precipitation studies upon MLWS growing medium to obtain primary data of how much rainwater MLWS's can proficiently eradicate, data of which could have been cross tabularized to previous scholars. However, the inability to access key apparatus required for testing and la ack of funding accessible did not permit this.

5.4 Further Research

To further the work of this academic dissertation the researcher recommends the following:

1. As observed, it is deduced that a lack of MLWS expertise originates at an educational level. Therefore, social and built environment investigations should take place to:

- Further triangulate the prerequisite to include the studying of MLWS's in further education.
 - To analyse at what point academics encounter MLWS's.
 - What the curriculum should include in reference to promoting other SUDS.
2. Future development of the devised mathematical formula should include the additional influences of:
- ML_O = Orientation,
 - ML_T = Temperature,
 - LW_E = Evaporation,
 - LW_{FV} = Flora variation.
3. As presented, cost comparisons between MLWS and the LTSSP were only devised for the Borough of Kensington & Chelsea. Supplementary research into generating a London-wide cost comparison would be beneficial to set a MLWS cost benchmark for future large-scale sewer infrastructure projects around the world. Finally, the maintenance costs associated with both systems must also be calculated and contrasted for further cost transparency.

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Appendices

Appendix A.1: The Script of Qualitative Interviews



Is the retro fitting of living wall systems on existing building stock is a cost-effective way to prevent pluvial localized flooding in UK cities?

Interview Questions:

Question 1: What previous experience do you have in constructing living wall systems?

"1" – Yes

"2" – No

Question 2: What was the client's motivation for incorporating a living wall system?

"1" – Sustainability & Biodiversity

"2" – Aesthetics

Question 3: During the tendering stage for the living wall system, were there many responses and how competitive were they?

"1" – Many

- Competitive
- Not Competitive

"2" – Not Many

Question 4: How was the system maintained post-completion?

"1" – Contracted

"2" – Independently

Question 5: How could the construction industry help promote living wall systems better?

"1" – Lower cost

"2" – Government Incentives

"3" – Planning Guidance

"4" – Promotion to Clients

"5" – Education

Question 6: Would you consider living wall systems as a cost-effective way of reducing rainwater run-off?

"1" – Yes

"2" – No

Question 7: Do you think government-backed financial incentives will help improve adaptation?

"1" – Yes

"2" – No

Question 8: What issues do you foresee for retrofitting such systems onto the UK's existing domestic housing stock?

"1" – Cost

"2" – Weight

"3" – Design Compatibility

"4" – Fire Safety

"5" – Planning Consent

Question 9: Do you think a living wall system improves the value of a property when considering its maintenance costs?

"1" – Yes

"2" – No

Question 10: Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory 'living wall' systems installed? (Where applicable)

"1" – Yes

"2" – No

Appendix A.2: Quantitative Questionnaire Design



IS THE RETROFITTING OF LIVING WALL SYSTEMS ON EXISTING BUILDING STOCK A COST-EFFECTIVE WAY TO PREVENT PLUVIAL LOCALIZED FLOODING IN UK CITIES?

You do not need pre-existing knowledge of Modular Living Wall Systems (MLWS's) to complete this questionnaire

Please tick the box(s) most relevant to you.

1. What is your occupation? (e.g. Project Manager, Quantity Surveyor, Contracts Manager, Ecologist, Construction/Engineering Student etc.)

2. Do you previously worked on a project concerning a Modular Living Wall System (MLWS)?

- ☐ Yes
☐ No

3. Have you encountered MLWS's at any point during your time in education?

- ☐ Yes
☐ No

4. What issues would you associate with MLWS's?

- ☐ Affordability
☐ Fire resistance
☐ Additional weight
☐ Building regulations and lack of common standards
☐ Maintenance and upkeep
☐ Reduced building comfort
☐ All the above

Page 1

5. Do you agree that MLWS's improve the value of a property?

☐

Yes

☐

No

☐

Not sure

6. Do you feel that the construction industry is doing enough to promote the implementation of MLWS's?

☐

Yes

☐

No

7. Should there be a government-backed incentive to retrofit MLWS's?

Strongly disagree				Strongly agree
1	2	3	4	5
☐	☐	☐	☐	☐

8. Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory MLWS's installed?

Strongly disagree				Strongly agree
1	2	3	4	5
☐	☐	☐	☐	☐

9. What benefits do you believe MLWS's bring?

- ☐ Suppression of soundwaves entering the structure
- ☐ Aesthetically pleasing
- ☐ Improved energy efficiency
- ☐ Increased biodiversity
- ☐ Improved user comfort
- ☐ Fire resistance
- ☐ Improved air quality
- ☐ Reduction in ground surface water
- ☐ All the above

10. What issues do you foresee for retrofitting such systems onto the UK's existing building stock?

Appendix A.3: Research Programme

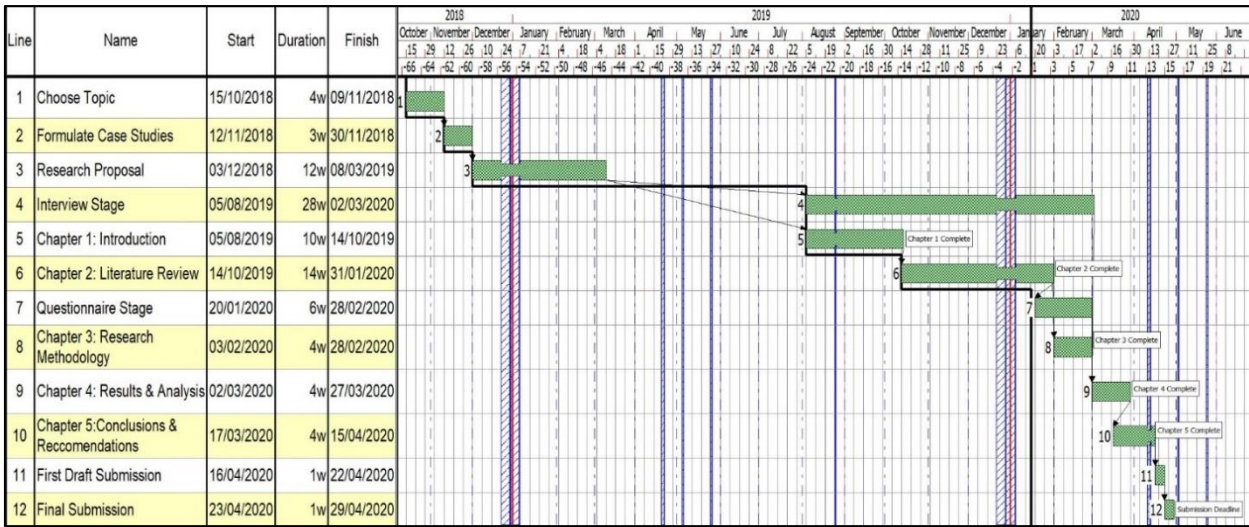


Figure A.1: Researchers programme to constructing a successful dissertation.

Appendix A.4: Interview Transcripts and Thematic Coding

Interview Respondent 1

Time & date: 4:00pm 7th August 2019

Location: HMT Sancta Maria Hospital, Ffynone Rd, Swansea SA1 6DF

Speaker [AM]: Question 1. What previous experience do you have in constructing living walls or living roof systems?

Speaker [DR]: The experience I have, a hospital project with the Bush hospital A&E in Haverfordwest. Where we a Sedum living roof back in 2009. Which was on a single-story building, one section single story, one section three stories. That's similar to what we're doing here now. But a single story had the living roof. Umm...trying to think of think why they chose the living roof. I think it was to do with drainage systems and it slowed it down . It slowed how quickly the water was drained off to help the drainage system, apparently, so yeah.

Speaker [AM]: My next question was going to be what was the client's motivation? So, it would have been to help with drainage?

Speaker [DR]: Yeah to help with drainage. It was one of those again, operationally, we don't get involved in the early schemes to see why they picked that. Why didn't they pick that? So, from an operations point of view, because I didn't work in the pre-construction, I wasn't part of any meetings that decided we're looking into using this system and the reasons ABC why they're looking to use it. I know it was due around drainage and how would that roof drains as it was a big roof. So how they control the water off that roof? Probably minimize the amount of outlets you would need rather than you know the water going on a flat roof and draining off very quickly.

Speaker [AM]: [PROBE] Did the structure go for BREEAM certification at all?

Speaker [DR]: It did go for BREEAM, yeah. BREEAM was fairly new back then so it was a BREEAM requirement. So, it would've been one of the credits we would've targeted .

Speaker [AM]: Q. What construction problems did you face, if any? Was it quite simple?

Speaker [DR]: It was quite simple really, yeah. It was like to be honest, what can I compare to, it was like to lay in turf, really. So you-you-you do look a sub grid, which is a good plastic system just laid down. There was a bit of clean stone clean gravel and then it was like basically this stuff came in trays, took it out of the tray and just threw it on a roof. It was like man turf in your garden.

Speaker [AM]: [PROBE] Because it is quite a heavy system would you have incorporated it with stronger trusses?

Speaker [DR]: It would have been the roof, the roof would have been designed to accommodate the weight because it is additional weight, because obviously one aspect is when

it is wet it is heavy. It was a concrete roof. But yeah, the roof on the structure was designed to take that additional weight.

Speaker [AM]: How could the construction industry help promote living roof and living wall systems better? because they are quite scarce, and they're only found on flagship -

Speaker [DR]: They are scarce yeah, I think a lot of it is **client driven**, so I think it's high end. It comes at a **cost**, so it depends on budgets. Depends on where you build the project I'm guessing, I know that they've done one on our last project, the IMPACT living wall. Which as I've said I wasn't involved in a great deal. **Whether, that would promote more because it looks quite good.** On the roof I did it. **Couldn't see it.** So, the actual benefits of it as in sort of, you know, for the appearance I mean you couldn't see it unless you were on the upper floors looking down.

Speaker [AM]: Would you consider living all the roof systems as a cost-effective way to reduce rainwater runoff?

Speaker [DR]: **Yes.** Yeah. I think as you say, I think that was one of the reasons why it was chosen on the project I worked on was to control rainwater.

Speaker [AM]: During the tendering stage, if you can remember that far back, were there many replies the tender? Were they competitive?

Speaker [DR]: It was a long time ago. All I remember is sitting in the meeting with the contractor that was installing it. We used a **contractor called Central Roofing and then they sub-let that work out to a specialist contractor** who came, give us a bit of a talk on the product, the benefits to, you know, of the property. They don't show any negatives because **they're trying to sell a system.** But I can't really remember what was discussed all I remember them saying is that the system comes in, say it's 25 to 50mm high. They say it'll never grow; I went back to years later and it was probably close to 500mm high.

Speaker [AM]: Did you find that there was a lack of expertise and common standards regarding the living systems? Because obviously it would've been your first one.

Speaker [DR]: **Yes,** I think it was. Yeah, we knew nothing about it. I knew nothing about it. As a company, I don't think we'd done a lot of it. And being so scarce, you don't get to become familiar with something unless you work with it all the time. But yeah, I did it on one project and that was 10 to 11 years ago. Not done one since. So, it just shows that they're not heavily popular.

Speaker [AM]: How is the system-maintained post completion, do you know?

Speaker [DR]: Well, I think it was it was it was supposed to have been not required to be maintained. I think that's one of the positives they said, but it doesn't need any maintenance because it's not supposed to grow. But I think what they forget is that you have birds who would potentially drop stuff on it seeds and different things. And then it does, it does grow. So, there is a **maintenance requirement** for

it which I don't think the hospital were aware of because they were probably told it was non-maintenance product.

Speaker [AM]: So, do you think that the government should back financial incentives to help improve the adaptation? Do you think that would be a positive?

Speaker [DR]: It would be a positive. And I think if the government were to back it, then people would probably promote it more if it's going to come out of a budget it's probably unlikely to go ahead. I say this budget hear for example, private client, clients going to obviously have a budget in mind. What's more important to him is the use of the building and the usability of the building. Living roofs and living walls probably wouldn't be the top of his agenda because he's a private client. And public sector would probably be different as they're spending other people's money rather than their own money.

Speaker [AM]: So, what issues would you foresee for the retrofitting of living walls and living roofs on existing building stock?

Speaker [DR]: Yes, I would say structural would be the main one. Umm...roof wouldn't be designed to take that extra load. So, it would be a lot of structural, additional structural work required to make a roof strong enough wall strong enough. Because you're hanging something off a wall, has it been designed for the weight? So that's the that's probably the biggest challenge I would say for walls and roofs especially you know, and it depends on the extent of it. How much if it was a smaller section, yeah, it would be less. It depends how much of it you would need for it become effective really isn't it. If it was a whole roof, it's a complete change of design. If it was a domestic property, have you got the space? So, it would be a lot of - a lot of work for that retrofit.

Speaker [AM]: And finally, would you like to work on more living wall or living roof projects in the future?

Speaker [DR]: I would, yeah. I would, yeah. Because, you know in our industry, we tend to do a lot of the same stuff. It is nice to do something different. You know, I have worked on one in 10 years. I probably showed quite a bit of interest and that because it was something new. Once you've done two or three I'd probably feel not as interesting, but it is nice to see something being done differently as long as it adds value, it's beneficial and you don't have any long-term problems with it. So that's what's important for us. As we don't want to be coming back to the project for something that's not as good as it says it is because there's not that many people to do it. So, you're sort of stuck who to use then because in what we do as in external facades, brickwork cladding there's a vast variety of people that can do that work for us so it's a very competitive market then. Where if there's only a few of them they can sort of charge what they want and could take advantage of the situation.

Speaker [DR]: It's definitely something I would like to work in. I've seen the living wall at IMPACT building, I think when I was there the guy came to just fit the first fix and just hands it on.

Speaker [AM]: [PROBE] Do you know what contractor that was?

Speaker [DR]: No, I don't .

Interview Respondent 2

Time & date: 4:00pm 7th August 2019

*Location: Swansea University Bay Campus Nanhyfer Building Estates Office, Fabian Way,
Crymlyn Burrows, Skewen, Swansea SA1 8EN*

Speaker [AM] What previous experience do you have in constructing LW/LR systems?

Speaker [MC] IMPACT is the first living wall I have done all the way through design and construction. I built another living wall on a building in Bristol, but I only oversaw the design period because I left the project before that came to site and I've done another living roof system in a primary school in Caerphilly; albeit not very big.

Speaker [AM] What was the client's motivation for incorporating a LW/LR system?

Speaker [MC] On IMPACT it is probably about it being a focal point for the university because of where IMPACT sits at the entrance to the campus, they wanted a showpiece basically. So, they obviously get some sort of environmental benefit from it in terms of enhancing biodiversity but they never really assessed that properly; so they never really got their ecologist to update reports so they were clearly not that interested in that aspect too much, the focal point bit was more of interest to them.

Speaker [AM] What construction problems did you face during the construction and design?

Speaker [MC] Okay, so we faced some problems with the cladding in that the cladding contractor didn't want the system directly bolted to their cladding panel. It wasn't a problem as we introduced a carrier system between the two to introduce an air gap; but that's a cost and coordination issue. So, some of the carrier railed got put in the wrong place because the coordination between the living wall contractor and the cladding contractor wasn't 100%; it was resolved, not the end of the world but that was bit of a lesson. The water supply was bit of a challenge, so you have to hook them up to a fresh water supply because they want to control the chemicals that are in the water, they don't want any contaminants coming off the roof or from any other systems so you've got to make sure they have a portable supply.

Power is okay, they need a relatively small power supply and then as you've seen from the site they need some space to put their equipment (cabinet) ideally we would have put it inside but that would've eaten too much into the footprint of the building so we wound up having to put this outside which entailed a difficult conversation about how far can it be because where it is now is the maximum distance it can be away from the living wall because the pumps cannot pump any further than that. We had some planning

problems which include the selection of the plants which was quite challenging. So, in a living wall system like this one you can't just pick whatever you want; you have to pick plants that will survive within the locality.

So, you've seen from the drawings that there are little pockets at an angle where all the plants are living, only certain species will survive in that environment. So, there is a relatively narrow species set that will actually survive in that environment. IMPACT's living wall is north facing, so you narrow that species set narrower again because there are only certain species that will survive in a north facing environment. And then, we are right next to an SSSI, so because we are right next to a SSSI you can't have any of those plants that could invade that SSSI. So, anything that's on the invasive species list or anything that is listed as a potential of going on the invasive species list has to be taken out of the system.

So, you can see you are limiting the number of plants that you can put into that quite significantly. Biotecture and the others (manufacturers) are good and they want to tell you what plants are best, but they don't really know because it depends on what you want to see. Do you want lush foliage or different colours and all this sort of stuff, so they don't really know so we had a lot of challenges going backwards and forwards working out what the best plants were with the university. It is subject to planning so we then put it to the planning officer and the planning officer said you don't have enough local species in the wall. You don't have any local species in the wall in fact, but he wouldn't tell us exactly what he wanted in the wall.

In the end we worked out what they wanted, and what they wanted was some of the species from the SSSI putting into the wall but we don't know if those species are going to survive in the wall because of these little pockets so we don't know if that is suitable for those particular plants. So what we've had to do within that living wall I think 30 plants that originate from the SSSI under the terms of the contract, biotecture are responsible for maintaining that wall for a year and then after that year the university will take over a maintenance contract with them. So, over those 12 months they do 4 visits and they prune all the plants and check the dosing of all the plants and replace any plants that have died.

So, we have an agreement that if those 30 or so plants from the SSSI survive that is brilliant, but if they die, the terms of the contract means that they will be replaced with one NOT from the SSSI and replaced with ones that we know survive. So potentially in a years' time those 30 plants will all be gone if they don't survive in a north facing living wall, if they do survive that is brilliant and they'll stay. But you can imagine that that is quite a difficult thing to get through planning because you've got lots of ifs and buts and planning and the client are every 'this is how it is' but to be saying,

well; this is what we'll do and if this happens we'll do this planning don't really like that.

So, I worked on IMPACT for 12 months out of the 76-week contract, so I did 54 weeks or something like that and I spent almost all the 54 weeks on this living wall. But you know things come and go, float backwards and forwards but almost the entirety was spent on this. I met biotecture for the first time within a couple of weeks of joining the project and was still talking to them after I left the project because we were still talking about key stuff. So, for a relatively small package it required an awful lot of work and a lot of coordination with a lot of other people

Speaker [AM] During the tendering stage for the LW/LR system, were there many responses and how competitive were they?

Speaker [MC] So I can't remember how many responses there were or how many companies we went to but normally you go to 3. But I couldn't tell you who the 3 were but when I joined the project we were just starting and beginning piling and we had already decided that biotecture were going to do it. So, we would've gone out for 3 because that's how the 2-stage tendering process works you have to get a minimum of 3 quotes. But there aren't many companies in the UK that do it so it does limit your opportunities. So, everyone has their own system, so biotecture and the drawing here are biotectures own system, other companies will have their own system. I think the one I did in Bristol had horizontal pockets rather than sloped.

PROBE [AM] What was the total cost for the system?

Speaker [MC] £70,000. This is for the construction and the installation and that bought 3 months maintenance with it. Were contracted for a 2 month defect period so we had a conversation with the client saying look; if we only have a 3 month warranty period and these plants start to die after 6 you're going to come back to us saying it a defect period and were going to say, sorry; you haven't maintained it.

So, we agreed with the client that we would do 12 months so we upgraded out maintenance to 12 months and that way £3,500. So that gives you a feel for how much it will cost the university post completion. It'll cost the university about £3,500 a year to maintain that system. But that buys them that guarantee that it will always be green, providing all the nutrients it needs, pruning and replacement plants if anything dies. The pruning is quite important because all of these plants will seed themselves over time, so if you want the living wall to look consistent you can't let them seed and if you want to prevent them from spreading seeds elsewhere like on the grass around the campus or into the SSSI then you'll have to prune them every 3 months. So, there is a planning

requirement that says for the rest of time, that this living wall will be maintained to prevent it from invading.

Speaker [AM] This is a big contractual risk.

Speaker [MC] If they start to put more living walls in, they'll have better contract terms because if you're maintaining two living walls or three living walls, they'll be better than if you are maintaining one. And they don't have to it Biotecture of course. Biotecture have put it in and they'll do the first year definitely. But you could then go to another company because these companies as well as doing the insulation they'll happily maintain someone else's wall as well because it is quite easy. It's a case of you would place the plants died, prune them and water them. It's not too difficult.

Speaker [AM] So, you said not many companies in the UK do this sort of stuff. So, when designing and constructing the living wall, did you find there's a lack of expertise and common standards? Were there many case studies you could look at and -?

Speaker [MC] So, we were quite lucky that because we already knew that Biotecture were going to do this from an early stage. We can engage them really early and make sure that the details that the architect was doing reflected their system. If we were still talking to three companies and everyone had like different system and or stuff, then that would've been more difficult because we would have been defining how everything works. And that then gives you a potential challenge in terms of making sure your building looks how you wanted to look.

PROBE [AM] So, if those that lines of communication between those two parties-

Speaker [MC] Yeah. And that is difficult if you cannot define who the other party is. So, if you can't say definitively it's Biotecture then taken a bit of a guess and the example there might be the depth of the soil pocket. So, for example, we knew how deep Biotectures build up was. So, we then know how far these fins need to stick out and how far this cladding reveal needs to stick out to give us that definition. So, it does not look like the wall is completely overpowering it. You imagine that these plants could easily grow over the top of the fins if we put them in the wrong place because we knew what Biotectures system build up was. We could draw that cladding panel, the build-up, and that gets us to this distance from here. So, we then know that these findings need to be about plus 50mm or whatever.

So, it helps knowing whereas with a different living wall system, that have deeper pockets that could have pushed all those plants further out and it would have lost aesthetic that they were looking for.

Speaker [AM] We've already touched on maintenance post completion. But how could the construction industry help promote living wall systems because currently they are only found on flagship facilities.

Speaker [MC] So, it's tough because I think they're **expensive**. It is tough because they're difficult to maintain or not so difficult. But certainly, there is an expense. So, if you are running, you know, a lot these buildings are funded by, so, impact is part **funded by WEFO**, which is the Welsh European Funding Office. So, the capital cost of the building is funded by someone else. It's brilliant so that's like 70 grand.

They found that, that was part of the budget and that's great. But three and a half thousand pounds a year-ish that they've got to maintain. They have got to find that university. They must find that money. So, three and half grand is not massive for a university, but you can see everything that drives up your maintenance costs on the building has an impact on your long term. **So, I think that that's part of the challenge is a lot of people don't necessarily on the maintenance. The idea of putting it in is brilliant and everyone loves it. But the idea of paying for it forever.**

It's a bit of a challenge, particularly because you cannot necessarily link it to something environmentally sustainable, so you cannot link it to your rainwater harvesting. Because they want to control the chemicals they are in it, and if there are any chemicals coming off the roof or if there's any contaminants come off the roof, it could kill the wall. **So therefore, you cannot even say, well, we will feed it with rainwater.** And, you know, well certainly not this system. So, you know, this system, there may be other systems out there where you can but not this system in particular. We could not do that. So, you are not even seeing that benefit of being able to use water or whatever.

So, I think it's interesting you were saying earlier, you think there's more potential for this than there is a roof. So, I think the other way around, I think roofs because you don't have to do anything with it. And they will absorb a certain amount of the rainwater. And even if they're not absorbing it, they will attenuate it. So they will slow it down from entering – so, I don't know if you know much about drainage, but will we do a lot of **attenuation systems** now where we slow down the speed at which rainwater enters the network to stop flooding? So, for example, if you have like a lot of rain for an hour, if that water all goes into the network, you might see it around your house. Sometimes the drains get overpowered and stuff like that.

Imagine a big building like impact or another big building that could easily flood an area. So, what we might do, we didn't have to do an impact, but we do elsewhere. You put a massive tank underground that holds all the water and slowly reintroduces it into the drainage network. So rather than it go in 25 or 30 litres a second into the sewer and overpower in the sewer, we hold it back and then

release it at maybe five litres a second or something like that. And that prevents the sewer from being overpowered.

Speaker [MC] This living wall system contributes nothing to that sort of thing . A living roof would because the water has to percolate. So, if you think about traditional roof being metal or whatever, the water lands on the roof , it works as way down into the gutters and down in the sewer. In a living roof system , it's probably got to that 30 centimetres of soil to work its way through and it percolates very slowly through. So that roof does absorb some of the water in its own right, but it also then slows down the rest of the water of the network . So .

Speaker [AM] Would you consider living wall systems as a cost-effective way of reducing rainwater runoff?

Speaker [MC] No. Roofs, maybe. But not wall systems.

Speaker [AM] Do you think government backed financial incentives will help improve adaptation?

Speaker [MC] Yeah, I think most people are prepared to take on big buildings. I'm not sure about. I'm not sure about some domestic stuff, but certainly big buildings, because your capital cost is often covered by someone else or you're not tending to be squeezing the pennies in quite the same way you are in the maintenance. I think if you can find a way to incentivize the maintenance bit of that. Then it could help. But again, I think it's got to be something that can be proven to make a difference, and I would have to be something in my view, based on my experience that would be something more like a roof rather than a wall. So, I don't think a wall can offer the benefit and therefore, I don't see that the government is going to put it. I think that they're better off legislating. So, I think if they legislate, which is sort of the SAB regulations and stuff like that, I think that would have more of an impact, rather than saying we're going to incentivize it. Rather than saying "you will do it or we're not going to be giving planning permission". Because the government hasn't got lots of money floating around. But most developers will find the money if they have to, so.

Speaker [AM] What issues do you foresee for retrofitting living wall systems into existing housing stock or commercial buildings?

Speaker [MC] Weight is a big one. I can see that something that would give much trouble to put that onto an existing building. They are quite heavy. And that's true for roofs as well. You put in a lot of soil and a lot of weight into a roof. So I could be a challenge.

Speaker [MC] It has slight concern about penetrating through waterproof line. And I was always a little bit worried about that at IMPACT because you've got that carrier panel. That is the waterproof line and the air proof line. And we're going to fix into it. You fixing into it in the right way, using silicon to tighten up use in rubber grommets to give you an air seal and then you've got the backing board that prevent

water. So, you've got plenty of things to stop it. But I was only always nervous with anything that we do. I'm always nervous about putting a screw through that waterproof line that's also true on brick buildings and stuff like that.

Anything that involves drilling into a system like that I'm always a little bit nervous about. I always worry slightly as well about introducing new cavities onto things because you can get mould and you can get damp and stuff forming. You sometimes see it when they do cavity wall insulation, they do it badly. They actually make problems worse in houses than they were before and that's not been tested. So, no one's really sort of done this sort of thing on a building on a large scale to find out if it's going to make a difference. The other thing we've done, if you've noticed on IMPACT, but there is an acre channel.

The water you irrigate it with does drip into an acre channel because they logically in order to keep the plants alive if they're going to feed it a little bit more water than actually needs rather than go the other way and not give it quite enough. And so there will always be water and you will see it at IMPACT. There is life starting to grow in that acre channel. It's just a little bit but it's a perfect environment. The water that is coming through has got some extra nutrients in it because it's been dosed by the system.

So, you have a potential for that. If the university don't maintain it to block up because it will let the plants are going to grow into the acre channel to block it up as well. So, you've got a wet thing at the base of your wall, which is okay in our case because we design the building around it. But if you're fit it to a old building, you don't necessarily know how that's going to interface with the building around you on the floor. And then you've got this maintenance thing. What if extra plant life grows and is it going to continue to grow?

Speaker [AM] Do you think that living wall systems improve the value of the property, given the maintenance costs and the potential for damp and other things?

Speaker [MC] It's like anything, isn't it? Depends on your buyer. So, on a house, I would bear towards no because the example I give is solar panels. So, when people put solar panels on their roofs, it doesn't necessarily increase the value. So, you would think, wouldn't you? If someone's invested 10 grand and put solar panels on the roof. You'd think that would increase the value of house or the desirability because you get free energy. But a lot of people are unfamiliar with it.

So, they don't know what the ongoing costs are. They don't really understand how it works. And they've never seen it on a house, and they don't know what to do. And they don't want that problem or even know what the problem out there might not be any problem but if something is unfamiliar to us. So, we don't necessarily want

that house, but there will be loads of people out there who do want that house. But I can see it being the same for living wall systems as well. I can see some people who would love it and absolutely want it on their house. But, I can see there being a lot of people going yeah, I'm interested because I don't understand it and I'm not sure what to do with it. I don't really want the maintenance cost.

You look at the living wall that's on the other building we looked at, that sort of thing is probably more manageable because you can see people might actually do their own weeding and it doesn't matter if it doesn't look perfect and stuff, but you can see something like IMPACT. If that started to look a bit tough and say 5 or 10 percent of the plants died it would look sporadic and crap, wouldn't it? So, I think it very much depends on the system. One is designed to be full and lush all year round and I think that would very quickly put people off.

The active classroom would be probably more appropriate for a house because that's probably a case of your water yourself, you could probably water that with a hosepipe. You know, we've seen there's an irrigation system, but that's probably a case of someone just turn the tap on once a week. You could probably water that with watering can or a hosepipe. So, that sort of thing probably has more potential and people can choose to do what they want with that. You can ignore it if they don't want anything on it or they can grow stuff on it.

Speaker [AM] Do you agree that all future government funded buildings, hospitals, schools have at least one compulsory living wall system installed?

Speaker [MC] No, no, no. Because I didn't like anything that's compulsory on a building because it drives you towards a particular architectural feature for one, but also it drives a certain maintenance and drives you to towards certain companies who are going to have to do stuff. You know, if Biotecture, I don't know how many companies are on the UK to do these things, but if you knew you were one of five companies in the UK that did it, you'd charge twice the cost or something. So, if you're saying, you must do this and we see this with so attenuation tanks, which have become a big thing in the last 10 years. The prices just keep going up and up and up and up.

And it's because there's only three or four companies that make them in the UK and they know they can put the price up because the competition is only a couple of companies. If there were thirty companies that did it, I think we'd see them being a lot cheaper.

PROBE [AM] That is what I thought. I thought maybe if it was compulsory with those incentives for it, there'd be a lot more companies starting up and therefore more competition.

Speaker [MC] That is probably true. That is very true. And that's what we saw with the solar panels. So, when the feed in tariffs came in with solar panels, suddenly there's loads of companies doing PV. And

when the green deal was flying around , there's loads of loads of companies starting up to do insulation on houses, PV systems at SLC pumps and stuff like that. So, it does drive when they change a big regulation like that. It does drive certain things.

But there is still that thing of people jumping on the bandwagon to make money because it's plenty of money. So, it would go up and then eventually come down, particularly for a system like this where I don't think it's actually driving any environmental benefit other than the biodiversity thing. But you do biodiversity differently as well . So, it's worth having a look at the SAB regulations and seeing how they drive. So, where SUDS is sustainable urban drainage system, the SAB is the SUDS Approval Body.

Interview Respondents 3 & 4

Time & date: 1:00pm 4th December 2019

Location: Neath Port Talbot County Borough Council, The Quays, Brunel Way, Briton Ferry, SA11 2GG

Speaker [AM] Question 1, did you find that there was a lack of expertise and common standards regarding the construction of living wall system?

Speaker [ZM] I would say **yes**. In terms of when we got to sites, I started on the project halfway through. So, all of the packages had been placed for the living wall. And I found that there was a there was a **knowledge gap between the cladding and system that would need to be installed**. And then the people who actually installed the living wall itself, so, the subcontractor who does the living wall, isn't actually the subcontractor who does all of the cladding rails and everything behind the system. So, I would say that there was a definite gap in knowledge between those two trades and between those two subcontractors when it came to the actual installation of the wall itself.

Speaker [MP] **Yes**. But people are **scared of them** people don't want to do them. People see them as a **massive barrier** and it's not necessarily a massive barrier. People just need to think about it and get **advice from the right people** regarding the right species for areas, especially on the coast with the bay campus.

Speaker [AM] How could the construction industry help promote living wall systems better?

Speaker [ZM] **Yes**. You need access in front of the water for people to get a little maintenance and repairs and clean. And you need. And a big enough area to have like a little plant room. Because you have got gas supply, water supply, you have got an electrical supply. So, you have got all of these cabins behind the scenes that nobody really sees when you look at the living wall itself. So, I would say to make it more appealing for the construction industry to use. They need to **actually explain** what goes on behind the scenes on it to **make it cheaper**.

PROBE [AM] What do you think the tipping point of affordability would be per square metre?

Speaker [ZM] My previous experience, the wall that **we constructed was around £700 per square meter**, so we were talking of an area of 116 metres squared. So, we had a big area to cover. **And for that cost it is a big ask**. And that is literally just for the one subcontractor. That doesn't include any of the costs for the cladding system and things that go on

behind it doesn't include any drainage costs, any electrical costs. And, you know, the plant room that is needed. That's all additional. So just for the actual wall in terms of plants and the sprinklers and everything that feed it. We were talking about 700 per square meter.

Speaker [MP] You've also got to maintain the wall don't forget, and if its tall you've got to get climbers going up to do the plants, so its not as simple as, a plants died and you have to replace it, its quite an effort, if a plants died at the top, you've got to maintain them ahead of prune etc.

Speaker [ZM] Which goes back to the, you need space in front of the wall to get a MEWP so someone can safely access the higher plants.

PROBE [AM] So, it was Biotechture that was the contractor who did it wasn't it?

Speaker [ZM] Yes.

PROBE [AM] Do they maintain the wall now do you know?

Speaker [ZM] Yes, they have a year's maintenance contract. But again, after that year maintenance its then down to the university to either re-employ them to come back and do it or they have to maintain it themselves.

Speaker [AM] OK. Do you think that government backed financial incentives will help improve adaptation?

Speaker [ZM] Yes, but in my opinion, I don't believe there's that much of a need for them.

Speaker [MP] No. The amount of effort that goes into maintaining a living wall, like the university one, one of them is not native species. So why are we putting non-native species on a wall, it doesn't help our biodiversity or wildlife. But if we use native species. It would be much better for everything. So, the living wall is basically for people. It's not for wildlife or pollinators. It appeals to people only. It is no good for other things.

There is a couple of walls at Swansea University which Ben Sampson is maintaining, and he's used them as a nursery for sea stock, which is we've got the of the only populations of sea stock in Wales and the UK almost. And he's had great success using as a nursery that, you know where the living classroom is in the uni. It's on one of the maybe active classrooms. He's got two or three walls. And he used as a nursery for kidney beans and native plants and he's had great success. But that's one thing. It doesn't look as attractive as your usual living wall because it's not green all year round, but biodiversity wise it's much better.

Speaker [ZM] Yeah. So, the one that we installed on the outside of the building at Swansea University. That was a north facing wall. So there were

certain plants that we couldn't put in there because they wouldn't thrive and wouldn't grow. So, it also limits as to where you can install it. An internal living wall is completely different to what you would do as an external living wall. So, no. I don't think even if the government said here's a sum of money. Everybody take it up. I don't think the people would do it because there is so much around it that's not just here's a green wall.

PROBE [AM] And you would not say that it would be financially worth it to see the energy reduction in the building, thermally speaking?

Speaker [ZM] I have reservations as to whether or not there is much of an impact because they say that it reduces its more insulated for the building and therefore it reduces the overall cost of heating. Because, you know, you build is better insulated. They I don't think there's been enough research yet to determine whether or not that really does have a financial impact. You know, the financial impact of maintaining the system, installing it, whether or not the benefits of having the build slightly more insulated pays off as a life cycle cost. I'm not sure whether or not they actually outweigh each other.

I don't think anybody's done it yet. I don't think they've had to living wall up long enough for people to actually calculate how much of an insulated it is, whether or not it does actually reduce the cost of the bills and maintain and run in the building.

Speaker [AM] What issues do you foresee for retrofitting such systems on UK existing building stock?

Speaker [ZM] I don't think it would be possible. I just can't see how you would go to a normal domestic household.

Speaker [MP] They would have enough space to make it, with all the plant and everything on the back into it. You take a lot of space up on the side of the house.

Speaker [ZM] Yeah. I do not think it'd be viable.

Speaker [AM] Do you think that a living wall system improves the value of property?

Speaker [ZM] No, I don't see what the difference of having a living wall on your house is to having lots of pumped pots and lots of, you know, greenery in your front garden or back garden. You know, the biodiversity element where you've got bees and pollination and everything like that. You don't need to living wall to achieve that. You need a healthy, thriving green garden, not an artificial grass. I was is a wonderful tool, but it's not only the cost of something.

Speaker [MP] But again, it's maintenance and that they have native species. That's the problem we face. They don't do native species and if it's not native species to us. **It's pointless.**

Speaker [AM] Do you agree that all future government funded buildings, schools and hospitals should have a compulsory living wall?

Speaker [ZM] **No.** I believe they should have a compulsory, which they were ready to, I believe, and that they have their targets there. They have to have "X" amount of space, which is, yes, to enhance biodiversity as a legal requirement.

Speaker [MP] **Now we have to enhance biodiversity. We can't just do nothing,** but instead of living walls, green roofs. We should go for green roofs instead of living walls as they're much easier to maintain and you can put better species in them.

Speaker [ZM] And I would say as a **counter argument, from another side to install a green roof is harder, because if you have a leak or if you have a penetration of the roof, to find where that water is coming in from is near enough impossible.** So again, back to the maintenance side, you've got a green roof and then all of a sudden you've got a drip coming in this corner of the room. That doesn't necessarily mean that the tear or the repair and the roof is going to be directly above. It could be the complete other end of the building. And it's just tracking down and it's just found a weak spot in the roof. And this is where it's coming through, which is the same principle for most flat roofs. So, any flat roof, you've got that same issue. In terms of, you know, water track in leaking. But if you stick soil and plants and everything else on top of that, you need a pretty hefty structure to take all of that weight.

Speaker [MP] Because I think it's something like **a hundred-twenty-five mill of substrate, you need a minimum for a green roof. So that's quite heavy.** It's like 200 kg per square metre load. But that has a lot of installation benefits for the building. And if you install it with solar panels, solar panels are better because the greenery underneath the solar panels keeps them cooler. Whereas if you've got solar panels on their own and a flat roof that overheats they will work as well, with the green element. It cools it down. So solar panels with much better. If you've got the roof added into the solar panels. So with the two technologies together it'd be a lot more cost effective.

Speaker [ZM] Yeah, **I would say a green roof is a better solution** to a living wall, a living wall is more, I would say for and a statically pleasing element, you **walk past and you see this like all fabulous green living wall and it's like, oh, wow, that looks lovely.** But actually what it gives back in biodiversity, what it gives back in insulation elements, I don't think it **actually weighs just that that wall looks pretty.**

Speaker [MP] It just pays off if people think about biodiversity and green, but it might not necessarily get the benefits unless you plant native species to begin with, which not many places do. Because down here we've got brownfield sites.

So, the old industrial spoil, they've got very strange little plants and they grow in stressed environments which you can perfectly shove on top of a roof. That is where they want to be. So, there is no issue with them being on the roof or on the floor. So for us, if we do green roofs, we can hit just as good biodiversity as we would on the floor, whereas with living walls not so much because obviously you've got the components, where there are troughs and things, but you can do a good species. It's just the maintenance announced that tends to be annuals. It'll die and not as pretty all year round, which people don't tend to want. They want to evergreen all year round.

Interview Respondent 5

Time & date: 2:00pm 18th December 2019

*Location: Swansea University Bay Campus Nanhyfer Building Estates Office, Fabian Way,
Crymlyn Burrows, Skewen, Swansea SA1 8EN*

Speaker [AM] How could the construction industry help promote living wall systems better?

Speaker [BS] How could they promote them? I think where there are companies that were providing living, where obviously they've got a vested interest in promoting them to clients. So, I guess it's getting the architects and the planners on board to try and be putting this forward at the earliest stages. And having spoken to a few people to do with this project and other ideas of green infrastructure in cities. Cost is obviously an issue I think. Whether the industry can do more to promote it. The conclusions that I heard a lot of people coming to and I'm not expert on this would be that they need to be pushed really by having sort of planning guidance that says you need to be putting them in place. Without that if it's more expensive, it might be different in places like London where property values are so high and putting these things on makes them very desirable and will pay for itself quite easily. A city like Swansea is a little bit different I think at the moment.

Speaker [AM] What do you consider living walls as a cost-effective way of reducing rainwater runoff?

Speaker [BS] Again, cost. I don't know. I've not looked at the figures. It will be reducing rainwater runoff. It's going to be reducing drainage costs overall in urban areas, whether it's the most cost-effective way or not. But it is certainly one of the tools that can be used to be slowing rainwater runoff and reducing flood risk.

Speaker [AM] Do you think living water systems improve the value of a property ?

Speaker [BS] I'm sure they would. Again, I don't have any data to me back-up. But, these buildings are attractive. They're more energy efficient. But I think just that from an aesthetic point of view and that they're going to be more desirable and therefore more valuable.

Speaker [AM] Do you think government-backed incentives will help improve adaptation?

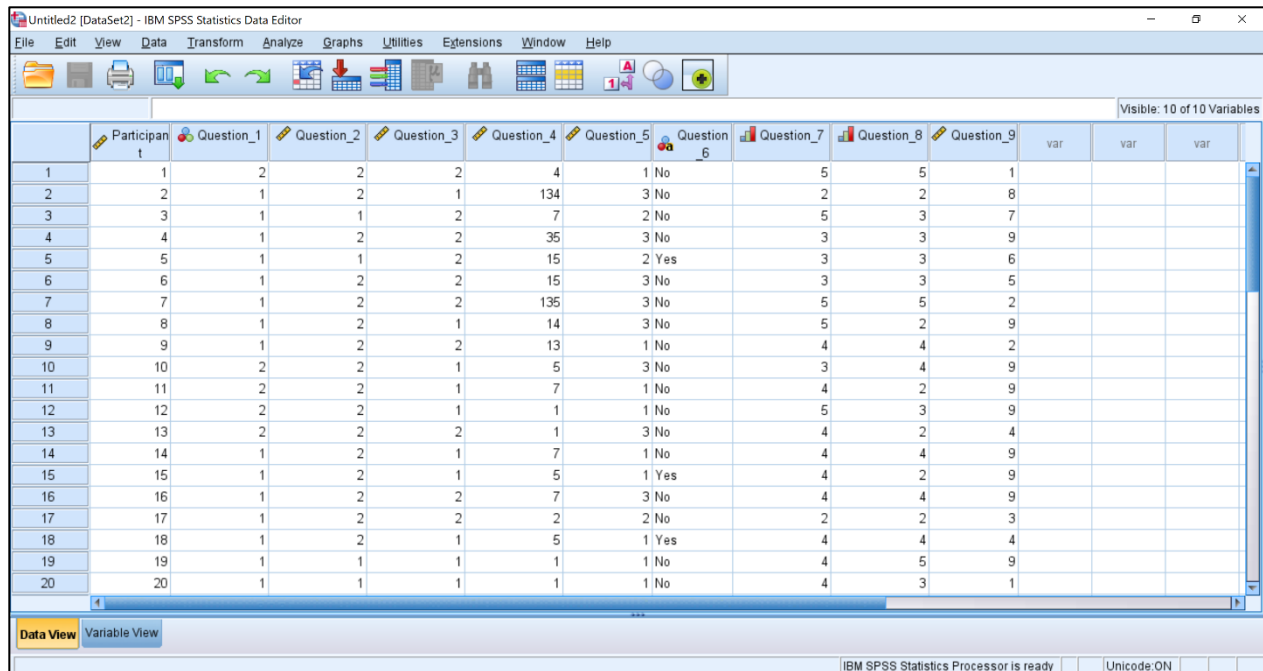
Speaker [BS] I should think so. Yeah. Yeah, I think that be a very important way to move forward.

Speaker [AM] And then finally, do you agree that all future government funded buildings should have a compulsory living wall system installed?

Speaker [BS] I think there should be very strong arguments for not having one. I mean, there may be situations where it's not appropriate. So maybe compulsory is too hard. But I think that yes. It'd be great if the emphasis was the expectation was that they would have unless it was a very strong reason not to.

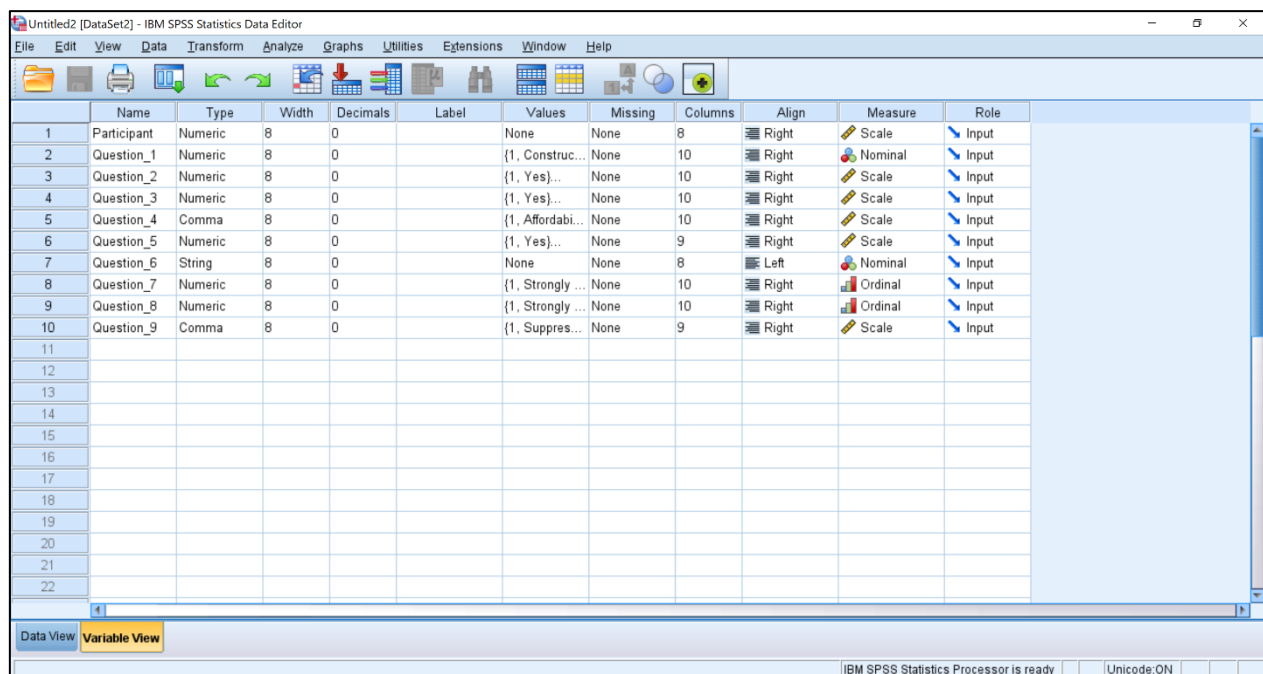
Appendix A.5: Data input into IBM SPSS.

All data from the following questionnaire responses had been inputted and displayed in *Figure A.2* for statistical analysis. *Figure A.3* illustrates the variable view from which coding values and measurement parameters were induced upon the data.



	Participant	Question_1	Question_2	Question_3	Question_4	Question_5	Question_6	Question_7	Question_8	Question_9	var	var	var
1	1	2	2	2	4	1 No		5	5	1			
2	2	1	2	1	134	3 No		2	2	8			
3	3	1	1	2	7	2 No		5	3	7			
4	4	1	2	2	35	3 No		3	3	9			
5	5	1	1	2	15	2 Yes		3	3	6			
6	6	1	2	2	15	3 No		3	3	5			
7	7	1	2	2	135	3 No		5	5	2			
8	8	1	2	1	14	3 No		5	2	9			
9	9	1	2	2	13	1 No		4	4	2			
10	10	2	2	1	5	3 No		3	4	9			
11	11	2	2	1	7	1 No		4	2	9			
12	12	2	2	1	1	1 No		5	3	9			
13	13	2	2	2	1	3 No		4	2	4			
14	14	1	2	1	7	1 No		4	4	9			
15	15	1	2	1	5	1 Yes		4	2	9			
16	16	1	2	2	7	3 No		4	4	9			
17	17	1	2	2	2	2 No		2	2	3			
18	18	1	2	1	5	1 Yes		4	4	4			
19	19	1	1	1	1	1 No		4	5	9			
20	20	1	1	1	1	1 No		4	3	1			

Figure A.2: Data view.



	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	Participant	Numeric	8	0		None	None	8	Right	Scale	Input
2	Question_1	Numeric	8	0		{1, Construc...	None	10	Right	Nominal	Input
3	Question_2	Numeric	8	0		{1, Yes}...	None	10	Right	Scale	Input
4	Question_3	Numeric	8	0		{1, Yes}...	None	10	Right	Scale	Input
5	Question_4	Comma	8	0		{1, Affordabi...	None	10	Right	Scale	Input
6	Question_5	Numeric	8	0		{1, Yes}...	None	9	Right	Scale	Input
7	Question_6	String	8	0		None	None	8	Left	Nominal	Input
8	Question_7	Numeric	8	0		{1, Strongly ...	None	10	Right	Ordinal	Input
9	Question_8	Numeric	8	0		{1, Strongly ...	None	10	Right	Ordinal	Input
10	Question_9	Comma	8	0		{1, Suppres...	None	9	Right	Scale	Input
11											
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22											

Figure A.3: Variable view.

Appendix A.6: Completed Questionnaires

Description: As reported, questionnaire fieldwork within this research was amassed in two differential formats. Firstly, the online application “SurveyMonkey” was employed where 21 online responses were registered, and secondly; questionnaires were additionally handed-out in a physical format, gathering 9 responses. Evidence of which are demonstrated below.

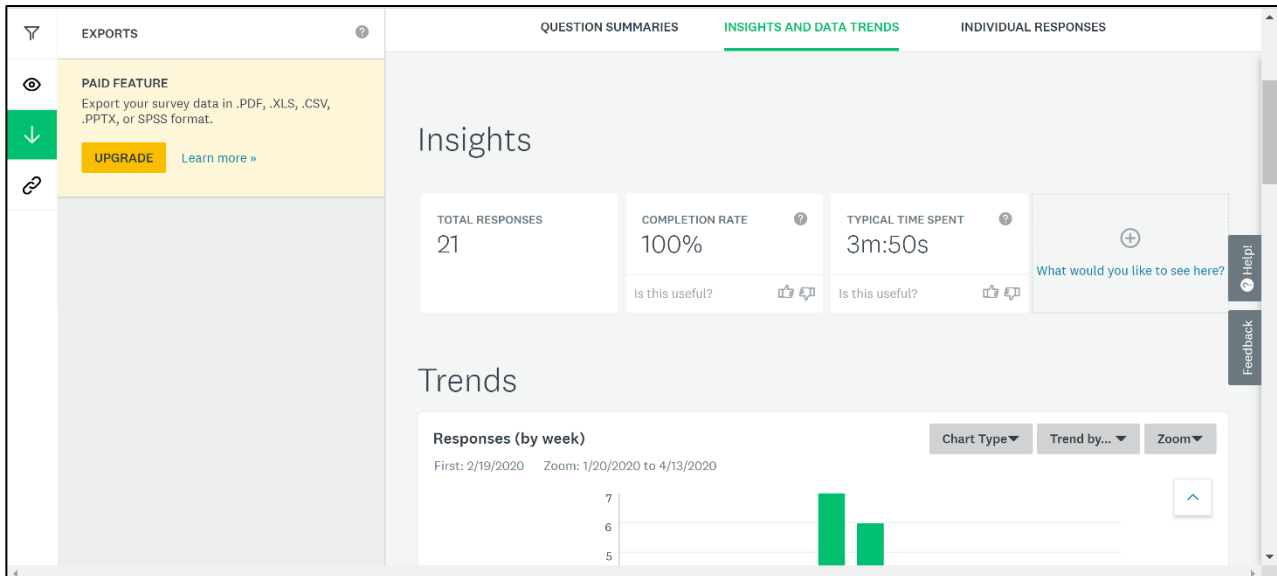
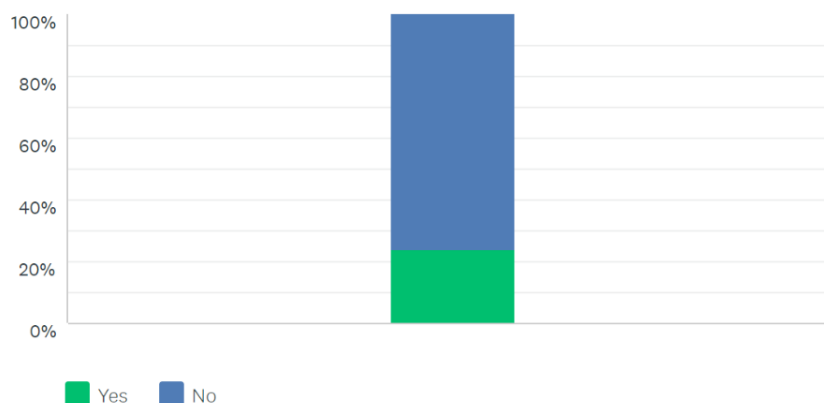


Figure A.2: Data extracted from 21 online respondents (SurveyMonkey, 2020).

Have you previously worked on a project concerning a Modular Living Wall System (MLWS)?

Answered: 21 Skipped: 0

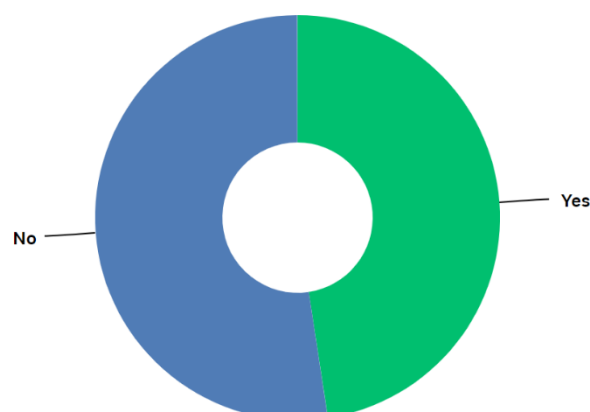


ANSWER CHOICES	RESPONSES	
Yes	23.81%	5
No	76.19%	16
TOTAL		21

Figure A.3: SurveyMonkey Q2 data summary.

Have you encountered MLWS's at any point during your time in education?

Answered: 21 Skipped: 0

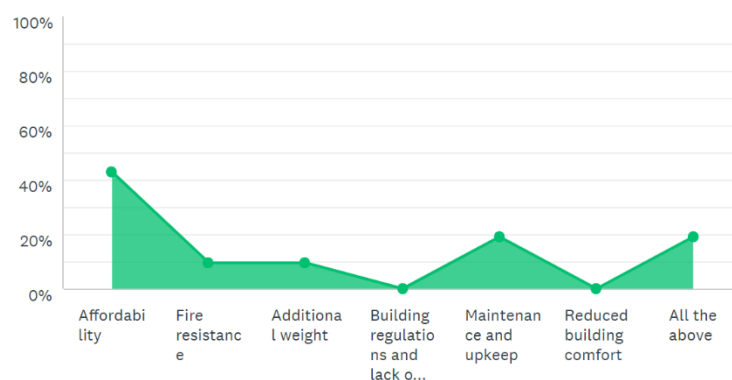


ANSWER CHOICES	RESPONSES
▼ Yes	47.62% 10
▼ No	52.38% 11
TOTAL	21

Figure A.4: SurveyMonkey Q3 data summary.

What issues would you associate with MLWS's?

Answered: 21 Skipped: 0

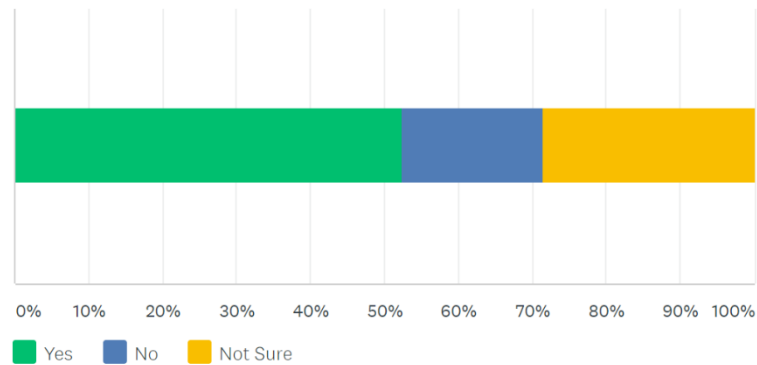


ANSWER CHOICES	RESPONSES
▼ Affordability	42.86% 9
▼ Fire resistance	9.52% 2
▼ Additional weight	9.52% 2
▼ Building regulations and lack of common standards	0.00% 0
▼ Maintenance and upkeep	19.05% 4
▼ Reduced building comfort	0.00% 0
▼ All the above	19.05% 4
TOTAL	21

Figure A.5: SurveyMonkey Q4 data summary.

Do you agree that MLWS’s improves the value of a property?

Answered: 21 Skipped: 0

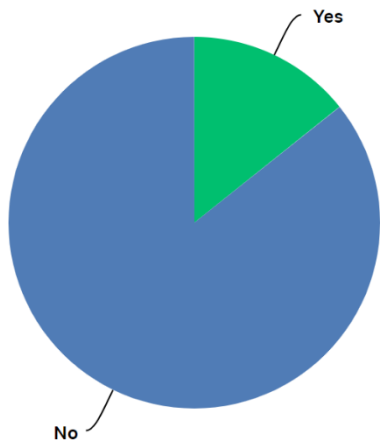


ANSWER CHOICES	RESPONSES	
Yes	52.38%	11
No	19.05%	4
Not Sure	28.57%	6
TOTAL		21

Figure A.6: SurveyMonkey Q5 data summary.

Do you feel that the construction industry is doing enough to promote the implementation of MLWS’s?

Answered: 21 Skipped: 0

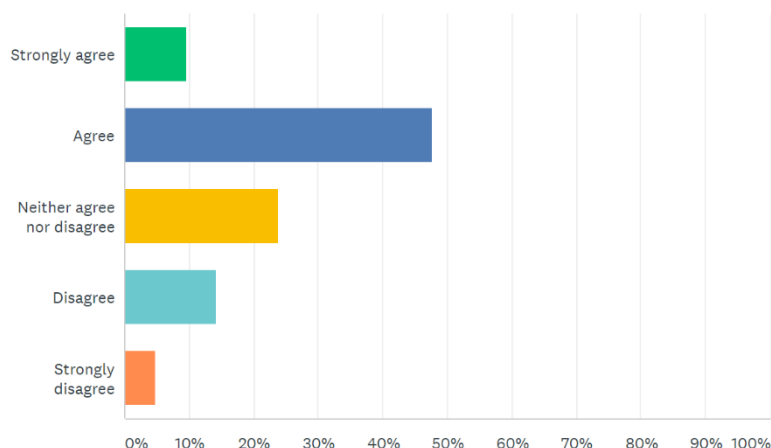


ANSWER CHOICES	RESPONSES	
Yes	14.29%	3
No	85.71%	18
TOTAL		21

Figure A.7: SurveyMonkey Q6 data summary.

Should there be a government-backed incentive to retrofit MLWS's?

Answered: 21 Skipped: 0

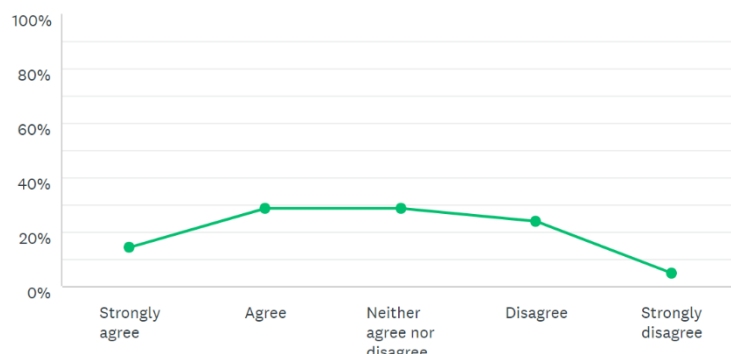


ANSWER CHOICES	RESPONSES	
Strongly agree	9.52%	2
Agree	47.62%	10
Neither agree nor disagree	23.81%	5
Disagree	14.29%	3
Strongly disagree	4.76%	1
TOTAL		21

Figure A.8: SurveyMonkey Q7 data summary.

Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory MLWS's installed?

Answered: 21 Skipped: 0

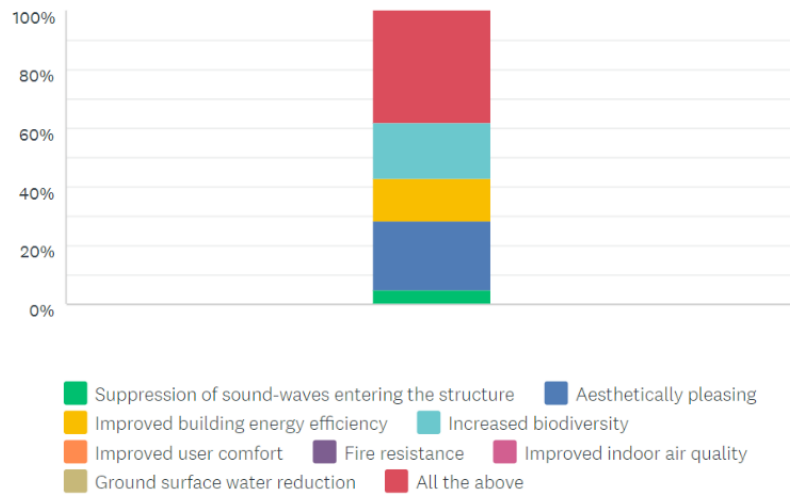


ANSWER CHOICES	RESPONSES	
Strongly agree	14.29%	3
Agree	28.57%	6
Neither agree nor disagree	28.57%	6
Disagree	23.81%	5
Strongly disagree	4.76%	1
TOTAL		21

Figure A.9: SurveyMonkey Q8 data summary.

What benefits do you believe MLWS's bring?

Answered: 21 Skipped: 0



ANSWER CHOICES	RESPONSES	
▼ Suppression of sound-waves entering the structure	4.76%	1
▼ Aesthetically pleasing	23.81%	5
▼ Improved building energy efficiency	14.29%	3
▼ Increased biodiversity	19.05%	4
▼ Improved user comfort	0.00%	0
▼ Fire resistance	0.00%	0
▼ Improved indoor air quality	0.00%	0
▼ Ground surface water reduction	0.00%	0
▼ All the above	38.10%	8
TOTAL		21

Figure A.10: SurveyMonkey Q9 data summary.

IS THE RETROFITTING OF LIVING WALL SYSTEMS ON EXISTING BUILDING STOCK A COST-EFFECTIVE WAY TO PREVENT PLUVIAL LOCALIZED FLOODING IN UK CITIES?

You do not need pre-existing knowledge of Modular Living Wall Systems (MLWS's) to complete this questionnaire

Please tick the box(s) most relevant to you.

1. What is your occupation? (e.g. Project Manager, Quantity Surveyor, Contracts Manager, Ecologist, Construction/Engineering Student etc.)

Management Trainee (construction)

2. Do you previously worked on a project concerning a Modular Living Wall System (MLWS)?

☐ Yes

☒ No

3. Have you encountered MLWS's at any point during your time in education?

☐ Yes

☒ No

4. What issues would you associate with MLWS's?

☐ Affordability

☐ Fire resistance

☐ Additional weight

☒ Building regulations and lack of common standards

☐ Maintenance and upkeep

☐ Reduced building comfort

☐ All the above

5. Do you agree that MLWS's improve the value of a property?

- ☒ Yes
☐ No
☐ Not sure

6. Do you feel that the construction industry is doing enough to promote the implementation of MLWS's?

- ☐ Yes
☒ No

7. Should there be a government-backed incentive to retrofit MLWS's?

Strongly disagree				Strongly agree
1	2	3	4	5
☐	☐	☐	☐	☒

8. Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory MLWS's installed?

Strongly disagree				Strongly agree
1	2	3	4	5
☐	☐	☐	☐	☒

9. What benefits do you believe MLWS's bring?

- ☐ Suppression of soundwaves entering the structure
- ☒ Aesthetically pleasing
- ☒ Improved energy efficiency
- ☐ Increased biodiversity
- ☐ Improved user comfort
- ☐ Fire resistance
- ☐ Improved air quality
- ☐ Reduction in ground surface water
- ☐ All the above

10. What issues do you foresee for retrofitting such systems onto the UK's existing building stock?

I don't see any issues.

/ 2

IS THE RETROFITTING OF LIVING WALL SYSTEMS ON EXISTING BUILDING STOCK A COST-EFFECTIVE WAY TO PREVENT PLUVIAL LOCALIZED FLOODING IN UK CITIES?

You do not need pre-existing knowledge of Modular Living Wall Systems (MLWS's) to complete this questionnaire

Please tick the box(s) most relevant to you.

1. What is your occupation? (e.g. Project Manager, Quantity Surveyor, Contracts Manager, Ecologist, Construction/Engineering Student etc.)

QS.

2. Do you previously worked on a project concerning a Modular Living Wall System (MLWS)?

☐ Yes
☒ No

3. Have you encountered MLWS's at any point during your time in education?

☒ Yes
☐ No

4. What issues would you associate with MLWS's?

☒ Affordability
☐ Fire resistance
☒ Additional weight
☒ Building regulations and lack of common standards
☐ Maintenance and upkeep
☐ Reduced building comfort
☐ All the above

5. Do you agree that MLWS's improve the value of a property?

- ☐ Yes
☐ No
☒ Not sure

6. Do you feel that the construction industry is doing enough to promote the implementation of MLWS's?

- ☐ Yes
☒ No

7. Should there be a government-backed incentive to retrofit MLWS's?

Strongly disagree					Strongly agree
1	2	3	4	5	
☐	☒	☐	☐	☐	

8. Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory MLWS's installed?

Strongly disagree					Strongly agree
1	2	3	4	5	
☐	☒	☐	☐	☐	

9. What benefits do you believe MLWS's bring?

- ☐ Suppression of soundwaves entering the structure
- ☒ Aesthetically pleasing
- ☐ Improved energy efficiency
- ☐ Increased biodiversity
- ☐ Improved user comfort
- ☐ Fire resistance
- ☐ Improved air quality
- ☐ Reduction in ground surface water
- ☒ All the above

10. What issues do you foresee for retrofitting such systems onto the UK's existing building stock?

Water, igneous.

3

IS THE RETROFITTING OF LIVING WALL SYSTEMS ON EXISTING BUILDING STOCK A COST-EFFECTIVE WAY TO PREVENT PLUVIAL LOCALIZED FLOODING IN UK CITIES?

You do not need pre-existing knowledge of Modular Living Wall Systems (MLWS's) to complete this questionnaire

Please tick the box(s) most relevant to you.

1. What is your occupation? (e.g. Project Manager, Quantity Surveyor, Contracts Manager, Ecologist, Construction/Engineering Student etc.)

SITE MANAGER.

2. Do you previously worked on a project concerning a Modular Living Wall System (MLWS)?

☒ Yes
☐ No

3. Have you encountered MLWS's at any point during your time in education?

☐ Yes
☒ No

4. What issues would you associate with MLWS's?

☐ Affordability
☐ Fire resistance
☐ Additional weight
☐ Building regulations and lack of common standards
☐ Maintenance and upkeep
☐ Reduced building comfort
☒ All the above



5. Do you agree that MLWS's improve the value of a property?

- ☐ Yes
☒ No
☐ Not sure

6. Do you feel that the construction industry is doing enough to promote the implementation of MLWS's?

- ☐ Yes
☒ No

7. Should there be a government-backed incentive to retrofit MLWS's?

Strongly disagree				Strongly agree
1	2	3	4	5
☐	☐	☐	☐	☒

8. Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory MLWS's installed?

Strongly disagree				Strongly agree
1	2	3	4	5
☐	☐	☒	☐	☐

9. What benefits do you believe MLWS's bring?

- ☐ Suppression of soundwaves entering the structure
- ☒ Aesthetically pleasing
- ☐ Improved energy efficiency
- ☐ Increased biodiversity
- ☐ Improved user comfort
- ☐ Fire resistance
- ☐ Improved air quality
- ☒ Reduction in ground surface water
- ☐ All the above

10. What issues do you foresee for retrofitting such systems onto the UK's existing building stock?

STRUCTURAL, IF THE EXISTING STRUCTURE CAN TAKE THE LOAD.

4

IS THE RETROFITTING OF LIVING WALL SYSTEMS ON EXISTING BUILDING STOCK A COST-EFFECTIVE WAY TO PREVENT PLUVIAL LOCALIZED FLOODING IN UK CITIES?

You do not need pre-existing knowledge of Modular Living Wall Systems (MLWS's) to complete this questionnaire

Please tick the box(s) most relevant to you.

1. What is your occupation? (e.g. Project Manager, Quantity Surveyor, Contracts Manager, Ecologist, Construction/Engineering Student etc.)

SITE MANAGER

2. Do you previously worked on a project concerning a Modular Living Wall System (MLWS)?

☐ Yes

☒ No

3. Have you encountered MLWS's at any point during your time in education?

☐ Yes

☒ No

4. What issues would you associate with MLWS's?

☐ Affordability

☐ Fire resistance

☒ Additional weight

☐ Building regulations and lack of common standards

☒ Maintenance and upkeep

☐ Reduced building comfort

☐ All the above

5. Do you agree that MLWS's improve the value of a property?

- ☐ Yes
☐ No
☒ Not sure

6. Do you feel that the construction industry is doing enough to promote the implementation of MLWS's?

- ☐ Yes
☒ No

7. Should there be a government-backed incentive to retrofit MLWS's?

Strongly disagree				Strongly agree
1	2	3	4	5
☐	☐	☒	☐	☐

8. Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory MLWS's installed?

Strongly disagree				Strongly agree
1	2	3	4	5
☐	☐	☒	☐	☐

9. What benefits do you believe MLWS's bring?

- ☒ Suppression of soundwaves entering the structure
- ☒ Aesthetically pleasing
- ☒ Improved energy efficiency
- ☐ Increased biodiversity
- ☐ Improved user comfort
- ☐ Fire resistance
- ☐ Improved air quality
- ☐ Reduction in ground surface water
- ☐ All the above

10. What issues do you foresee for retrofitting such systems onto the UK's existing building stock?

COST & SUTABILITY OF THE SUBSTRUCTURE

5

IS THE RETROFITTING OF LIVING WALL SYSTEMS ON EXISTING BUILDING STOCK A COST-EFFECTIVE WAY TO PREVENT PLUVIAL LOCALIZED FLOODING IN UK CITIES?

You do not need pre-existing knowledge of Modular Living Wall Systems (MLWS's) to complete this questionnaire

Please tick the box(s) most relevant to you.

1. What is your occupation? (e.g. Project Manager, Quantity Surveyor, Contracts Manager, Ecologist, Construction/Engineering Student etc.)

Site Manager

2. Do you previously worked on a project concerning a Modular Living Wall System (MLWS)?

☐ Yes

☐ No

☒ Other

Similar Green Wall where planting occurred at top of Retaining wall. Plant where to grow downwards - Bee Canes etc were added for ecology & BREAM.

3. Have you encountered MLWS's at any point during your time in education?

☐ Yes

☒ No

Generated in 2006.

4. What issues would you associate with MLWS's?

☒ Affordability

☐ Fire resistance

☐ Additional weight

☐ Building regulations and lack of common standards

☒ Maintenance and upkeep

☐ Reduced building comfort

☐ All the above

- Cost in obtaining Broom Rating



5. Do you agree that MLWS's improve the value of a property?

- ☐ Yes
☒ No
☐ Not sure

6. Do you feel that the construction industry is doing enough to promote the implementation of MLWS's?

- ☒ Yes - *through Bream.*
☐ No

7. Should there be a government-backed incentive to retrofit MLWS's?

Strongly disagree				Strongly agree
1	2	3	4	5
☐	☐	☒	☐	☐

8. Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory MLWS's installed?

Strongly disagree				Strongly agree
1	2	3	4	5
☐	☐	☒	☐	☐

9. What benefits do you believe MLWS's bring?

- ☐ Suppression of soundwaves entering the structure
- ☒ Aesthetically pleasing
- ☐ Improved energy efficiency
- ☒ Increased biodiversity
- ☐ Improved user comfort
- ☐ Fire resistance
- ☐ Improved air quality
- ☐ Reduction in ground surface water
- ☐ All the above

10. What issues do you foresee for retrofitting such systems onto the UK's existing building stock?

Substrate Not Suitable to receive
check Design Loadings on frame NOT suitable?

IS THE RETROFITTING OF LIVING WALL SYSTEMS ON EXISTING BUILDING STOCK A COST-EFFECTIVE WAY TO PREVENT PLUVIAL LOCALIZED FLOODING IN UK CITIES?

You do not need pre-existing knowledge of Modular Living Wall Systems (MLWS's) to complete this questionnaire

Please tick the box(s) most relevant to you.

1. What is your occupation? (e.g. Project Manager, Quantity Surveyor, Contracts Manager, Ecologist, Construction/Engineering Student etc.)

Quantity Surveyor

2. Do you previously worked on a project concerning a Modular Living Wall System (MLWS)?

☐ Yes
☒ No

3. Have you encountered MLWS's at any point during your time in education?

☐ Yes
☒ No

4. What issues would you associate with MLWS's?

☒ Affordability
☐ Fire resistance
☐ Additional weight
☐ Building regulations and lack of common standards
☒ Maintenance and upkeep
☐ Reduced building comfort
☐ All the above

5. Do you agree that MLWS's improve the value of a property?

- ☐ Yes
☐ No
☒ Not sure

6. Do you feel that the construction industry is doing enough to promote the implementation of MLWS's?

- ☐ Yes
☒ No

7. Should there be a government-backed incentive to retrofit MLWS's?

Strongly disagree				Strongly agree
1	2	3	4	5
☐	☐	☒	☐	☐

8. Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory MLWS's installed?

Strongly disagree				Strongly agree
1	2	3	4	5
☐	☐	☒	☐	☐

9. What benefits do you believe MLWS's bring?

- ☐ Suppression of soundwaves entering the structure
- ☐ Aesthetically pleasing
- ☒ Improved energy efficiency
- ☐ Increased biodiversity
- ☐ Improved user comfort
- ☐ Fire resistance
- ☒ Improved air quality
- ☐ Reduction in ground surface water
- ☐ All the above

10. What issues do you foresee for retrofitting such systems onto the UK's existing building stock?

Cost

IS THE RETROFITTING OF LIVING WALL SYSTEMS ON EXISTING BUILDING STOCK A COST-EFFECTIVE WAY TO PREVENT PLUVIAL LOCALIZED FLOODING IN UK CITIES?

You do not need pre-existing knowledge of Modular Living Wall Systems (MLWS's) to complete this questionnaire

Please tick the box(s) most relevant to you.

1. What is your occupation? (e.g. Project Manager, Quantity Surveyor, Contracts Manager, Ecologist, Construction/Engineering Student etc.)

Quantity Surveyor

2. Do you previously worked on a project concerning a Modular Living Wall System (MLWS)?

☐ Yes

☒ No

3. Have you encountered MLWS's at any point during your time in education?

☐ Yes

☒ No

4. What issues would you associate with MLWS's?

☒ Affordability

☐ Fire resistance

☒ Additional weight

☐ Building regulations and lack of common standards

☒ Maintenance and upkeep

☐ Reduced building comfort

☐ All the above

5. Do you agree that MLWS's improve the value of a property?

- ☐ Yes
☐ No
☒ Not sure

6. Do you feel that the construction industry is doing enough to promote the implementation of MLWS's?

- ☐ Yes
☒ No

7. Should there be a government-backed incentive to retrofit MLWS's?

Strongly disagree					Strongly agree
1	2	3	4	5	
☐	☐	☐	☐	☒	

8. Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory MLWS's installed?

Strongly disagree					Strongly agree
1	2	3	4	5	
☐	☐	☐	☐	☒	

9. What benefits do you believe MLWS's bring?

- ☐ Suppression of soundwaves entering the structure
- ☒ Aesthetically pleasing
- ☐ Improved energy efficiency
- ☒ Increased biodiversity
- ☐ Improved user comfort
- ☐ Fire resistance
- ☒ Improved air quality
- ☐ Reduction in ground surface water
- ☐ All the above

10. What issues do you foresee for retrofitting such systems onto the UK's existing building stock?

Existing structures may not be able to accommodate the additional weight.
There may be additional services & drainage required? This could be costly depending on existing landscaping.

8

IS THE RETROFITTING OF LIVING WALL SYSTEMS ON EXISTING BUILDING STOCK A COST-EFFECTIVE WAY TO PREVENT PLUVIAL LOCALIZED FLOODING IN UK CITIES?

You do not need pre-existing knowledge of Modular Living Wall Systems (MLWS's) to complete this questionnaire

Please tick the box(s) most relevant to you.

1. What is your occupation? (e.g. Project Manager, Quantity Surveyor, Contracts Manager, Ecologist, Construction/Engineering Student etc.)

Architectural Technologist

2. Do you previously worked on a project concerning a Modular Living Wall System (MLWS)?

☐ Yes
☒ No

3. Have you encountered MLWS's at any point during your time in education?

☒ Yes
☐ No

4. What issues would you associate with MLWS's?

☒ Affordability
☐ Fire resistance
☐ Additional weight
☒ Building regulations and lack of common standards
☐ Maintenance and upkeep
☐ Reduced building comfort
☐ All the above

5. Do you agree that MLWS's improve the value of a property?

- ☐ Yes
☐ No
☒ Not sure

6. Do you feel that the construction industry is doing enough to promote the implementation of MLWS's?

- ☐ Yes
☒ No

7. Should there be a government-backed incentive to retrofit MLWS's?

Strongly disagree 1	2	3	4	Strongly agree 5
☐	☐	☐	☐	☒

8. Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory MLWS's installed?

Strongly disagree 1	2	3	4	Strongly agree 5
☐	☒	☐	☐	☐

9. What benefits do you believe MLWS's bring?

- ☐ Suppression of soundwaves entering the structure
- ☐ Aesthetically pleasing
- ☐ Improved energy efficiency
- ☐ Increased biodiversity
- ☐ Improved user comfort
- ☐ Fire resistance
- ☐ Improved air quality
- ☐ Reduction in ground surface water
- ☒ All the above

10. What issues do you foresee for retrofitting such systems onto the UK's existing building stock?

People need to be educated regarding the benefits of MLWS in order for it to become more popular.

IS THE RETROFITTING OF LIVING WALL SYSTEMS ON EXISTING BUILDING STOCK A COST-EFFECTIVE WAY TO PREVENT PLUVIAL LOCALIZED FLOODING IN UK CITIES?

You do not need pre-existing knowledge of Modular Living Wall Systems (MLWS's) to complete this questionnaire

Please tick the box(s) most relevant to you.

1. What is your occupation? (e.g. Project Manager, Quantity Surveyor, Contracts Manager, Ecologist, Construction/Engineering Student etc.)

Construction Manager.

2. Do you previously worked on a project concerning a Modular Living Wall System (MLWS)?

☐ Yes
☒ No

3. Have you encountered MLWS's at any point during your time in education?

☐ Yes
☒ No

4. What issues would you associate with MLWS's?

☒ Affordability
☐ Fire resistance
☒ Additional weight
☐ Building regulations and lack of common standards
☐ Maintenance and upkeep
☐ Reduced building comfort
☐ All the above

5. Do you agree that MLWS's improve the value of a property?

- ☒ Yes
☐ No
☐ Not sure

6. Do you feel that the construction industry is doing enough to promote the implementation of MLWS's?

- ☐ Yes
☒ No

7. Should there be a government-backed incentive to retrofit MLWS's?

Strongly disagree					Strongly agree
1	2	3	4	5	
☐	☐	☐	☒	☐	

8. Do you agree that all future government-funded buildings (e.g. hospitals, schools) should have compulsory MLWS's installed?

Strongly disagree					Strongly agree
1	2	3	4	5	
☐	☐	☐	☒	☐	

9. What benefits do you believe MLWS's bring?

- ☐ Suppression of soundwaves entering the structure
- ☒ Aesthetically pleasing
- ☐ Improved energy efficiency
- ☒ Increased biodiversity
- ☐ Improved user comfort
- ☐ Fire resistance
- ☒ Improved air quality
- ☐ Reduction in ground surface water
- ☐ All the above

10. What issues do you foresee for retrofitting such systems onto the UK's existing building stock?

They would need to be constructed correctly
in order to prevent damp issues.

Appendix A.7: Spearman's Rho Table and Grading Standards

Source: Real-Statistics (2015) Spearman's Rho Table. Available at: <http://www.real-statistics.com/statistics-tables/spearman-s-rho-table/> (Accessed 17th April 2020).

$n \backslash \alpha$	0.2	0.1	0.05	0.02	0.01	0.002		$n \backslash \alpha$	0.2	0.1	0.05	0.02	0.01	0.002
4	1.000	1.000	—	—	—	—		18	0.317	0.401	0.472	0.550	0.600	0.692
5	0.800	0.900	1.000	1.000	—	—		19	0.309	0.391	0.460	0.535	0.584	0.675
6	0.657	0.829	0.886	0.943	1.000	—		20	0.299	0.380	0.447	0.522	0.570	0.662
7	0.571	0.714	0.786	0.893	0.929	1.000		21	0.292	0.370	0.436	0.509	0.556	0.647
8	0.524	0.643	0.738	0.833	0.881	0.952		22	0.284	0.361	0.425	0.497	0.544	0.633
9	0.483	0.600	0.700	0.783	0.833	0.917		23	0.278	0.353	0.416	0.486	0.532	0.621
10	0.455	0.564	0.648	0.745	0.794	0.879		24	0.271	0.344	0.407	0.476	0.521	0.609
11	0.427	0.536	0.618	0.709	0.755	0.845		25	0.265	0.337	0.398	0.466	0.511	0.597
12	0.406	0.503	0.587	0.678	0.727	0.818		26	0.259	0.331	0.390	0.457	0.501	0.586
13	0.385	0.484	0.560	0.648	0.703	0.791		27	0.255	0.324	0.383	0.449	0.492	0.576
14	0.367	0.464	0.538	0.626	0.679	0.771		28	0.250	0.318	0.375	0.441	0.483	0.567
15	0.354	0.446	0.521	0.604	0.654	0.750		29	0.245	0.312	0.368	0.433	0.475	0.558
16	0.341	0.429	0.503	0.582	0.635	0.729		30	0.240	0.306	0.362	0.425	0.467	0.549
17	0.328	0.414	0.488	0.566	0.618	0.711								

Grading Standards

Correlation Degree

$\rho = 0$	no correlation
$0 < \rho \leq 0.19$	very weak
$0.20 \leq \rho \leq 0.39$	weak
$0.40 \leq \rho \leq 0.59$	moderate
$0.60 \leq \rho \leq 0.79$	strong
$0.80 \leq \rho \leq 1.00$	very strong
1.00	monotonic correlation

Table A.11: Spearman's rho table and grading standards used for cross-tabulation with SPSS results (Real-Statistics, 2015).

Appendix A.8: Chi-Square Distribution Table.

Source: T-Table (2015) Chi Square Distribution Table. Available at: <http://www.ttable.org/chi-square-table.html> (Accessed 15th March 2020).

Degrees of Freedom	Chi-Square (χ^2) Distribution							
	Area to the Right of Critical Value							
	0.99	0.975	0.95	0.90	0.10	0.05	0.025	0.01
1	—	0.001	0.004	0.016	2.706	3.841	5.024	6.635
2	0.020	0.051	0.103	0.211	4.605	5.991	7.378	9.210
3	0.115	0.216	0.352	0.584	6.251	7.815	9.348	11.345
4	0.297	0.484	0.711	1.064	7.779	9.488	11.143	13.277
5	0.554	0.831	1.145	1.610	9.236	11.071	12.833	15.086
6	0.872	1.237	1.635	2.204	10.645	12.592	14.449	16.812
7	1.239	1.690	2.167	2.833	12.017	14.067	16.013	18.475
8	1.646	2.180	2.733	3.490	13.362	15.507	17.535	20.090
9	2.088	2.700	3.325	4.168	14.684	16.919	19.023	21.666
10	2.558	3.247	3.940	4.865	15.987	18.307	20.483	23.209
11	3.053	3.816	4.575	5.578	17.275	19.675	21.920	24.725
12	3.571	4.404	5.226	6.304	18.549	21.026	23.337	26.217
13	4.107	5.009	5.892	7.042	19.812	22.362	24.736	27.688
14	4.660	5.629	6.571	7.790	21.064	23.685	26.119	29.141
15	5.229	6.262	7.261	8.547	22.307	24.996	27.488	30.578
16	5.812	6.908	7.962	9.312	23.542	26.296	28.845	32.000
17	6.408	7.564	8.672	10.085	24.769	27.587	30.191	33.409
18	7.015	8.231	9.390	10.865	25.989	28.869	31.526	34.805
19	7.633	8.907	10.117	11.651	27.204	30.144	32.852	36.191
20	8.260	9.591	10.851	12.443	28.412	31.410	34.170	37.566
21	8.897	10.283	11.591	13.240	29.615	32.671	35.479	38.932
22	9.542	10.982	12.338	14.042	30.813	33.924	36.781	40.289
23	10.196	11.689	13.091	14.848	32.007	35.172	38.076	41.638
24	10.856	12.401	13.848	15.659	33.196	36.415	39.364	42.980
25	11.524	13.120	14.611	16.473	34.382	37.652	40.646	44.314
26	12.198	13.844	15.379	17.292	35.563	38.885	41.923	45.642
27	12.879	14.573	16.151	18.114	36.741	40.113	43.194	46.963
28	13.565	15.308	16.928	18.939	37.916	41.337	44.461	48.278
29	14.257	16.047	17.708	19.768	39.087	42.557	45.722	49.588
30	14.954	16.791	18.493	20.599	40.256	43.773	46.979	50.892

Table A.12: Chi-Square table used for cross-tabulation with SPSS results (T-Table, 2015).

SurveyMonkey Question 10 Response Coding

"What issues do you foresee for retrofitting such systems onto the UK's existing building stock?"

Respondent 10: Finding a way to retrofit the systems without **damaging the building**, water drainage, walls breathability, mould, **maintenance**

Respondent 11: It would require a **huge investment** from somebody's part and the **maintenance/Upkeep costs** may not be worth it in the long run for certain areas of the U.K.

Respondent 12: **Damp** and **lack of government backed incentives**

Respondent 13: The **expense** of the walls

Respondent 14: Difficulty in evidencing the ability of the existing building structure to withstand additional **load of living wall installation**, particularly in older buildings. Difficulty in accommodating the necessary **plant/ equipment within the confines** of the existing building structure. Difficulty in obtaining **planning consent** for living wall installation in certain areas. Reluctance of building owners/ managers to provide **funding** for installation of living wall where there is already a high demand for funding in order to carry out planned/ preventative **maintenance** works to the existing building.

Respondent 15: Most of the pre-1945 building stock **may not be suitable** for the installation of such systems. If the government bring forward grants for the installations of such systems but don't regulate the installers then further issues with **maintenance** and product failure may cause more harm than good.

Respondent 16: **Convincing clients, building owners** and others the benefits of such systems.

Respondent 17: Understanding the **anticipated lifetime** and costs associated with **maintaining/renewing/replacing** them

Respondent 18: It may reduce the **adaptability** of properties and their required uses

Respondent 19: **Short term affordability** and justification of the long-term value for Tenants and Landlords. Linked to this is awareness both of clients and trades when installing. Retrofit may also **create issues with the existing equilibrium** of buildings as certain areas /spaces **not designed to accommodate** these systems with increased moisture levels, potential for leaks and **long-term maintenance liability**.

Respondent 20: Every existing building will need to be assessed in relation to **structural integrity** of the building prior to installation. From a commercial & contractual perspective, further investigation into **warranty & liability** will need more in-depth consideration.

Respondent 21: Introduction of **additional weight** into a facade system. Risk associated with attaching a system that holds water against a facade system that may not have been designed to take it. Additional **cost burden** on buildings that may not have the budget to adequately **maintain** it.

Respondent 22: Compatibility.

Respondent 23: Suitability of existing buildings and there would be a reluctance from existing building owners to maintain if it is forced upon them. New build owners have made their own positive decision to include a living wall and so are also committing to the ongoing maintenance regime and cost.

Respondent 24: May not look right on an existing building.

Respondent 25: Long term maintenance being affordable by the 'End User' - after the initial maintenance and defects period elapses.

Respondent 26: Existing infrastructure and layout of current buildings ie drainage, floor levels, limited space between buildings. The current UK's Building stock age i feel could also be an issue as there are limited modern buildings that have the potential to not be able to withstand the ability to retrofit such systems. Planning issues potentially. The UK's ever-changing climate and choosing the correct species to survive.

Respondent 27: Lack of education, purchasers have little knowledge about the installation, cost, or benefits of Living Walls.

Respondent 28: Lack of affordability.

Respondent 29: Fire safety problems.

Respondent 30: Older buildings not being able to adapt to the new technologies.

Appendix A.10: London Tideway Super Sewer Project (LTSSP) Kensington & Chelsea Borough cost.

Source: Thames Water (2013) *Sewer Separation Feasibility Study Final Report*. Available at: https://infrastructure.planninginspectorate.gov.uk/wpcontent/ipc/uploads/projects/WW010001/WW0100010012758.3_Needs_Report_Appendix_D_Sewer_Separation_Feasibility_Study_Final_Report.pdf (Accessed 12th March 2020).

Frogmore Buckhold Road – Surface Water System:

Level 1 - Spine system				
Item	Construction Costs	Ratio (£ cost: Kg CO ₂)	Ratio Reduction Factor	Kg CO ₂
Opencut	£9,464,785	0.825	0.74	7,027,600
Tunnelling	£14,139,652	0.305	0.27	3,881,300
PS				
Civil	£12,358,500	0.345	0.31	3,837,300
M&E	£6,937,403	0.042	0.04	262,200
Overflows/Outfalls	£168,761	0.373	0.34	56,700
Sub total	£43,069,101			15,065,100
Level 2 - Sub-catchment				
Item	Construction Costs	Ratio (£ cost: Kg CO ₂)	Ratio Reduction Factor	Kg CO ₂
Opencut	£37,773,365	0.825	0.74	28,046,700
Opencut short length (gullies)	£462,042	0.907	0.82	377,200
Tunnelling	£0	0.305	0.27	0
PS				
Civil	£1,592,740	0.345	0.31	494,500
M&E	£57,322	0.042	0.04	2,200
Sub total	£39,885,468			28,920,600
Level 3 - Property Connections				
Item	Construction Costs	Ratio (£ cost: Kg CO ₂)	Ratio Reduction Factor	Kg CO ₂
Opencut short length	£36,599,625	0.907	0.82	29,876,300
Sub total	£36,599,625			29,876,300
Frogmore Total:				73,862,000

Table A.13: Appendix A.8 illustrates the high cost (£73,862,000) of the Kensington & Chelsea segment of the LTSSP (Thames Water, 2013).