WHAT ARE THE PROSPECTS FOR REDUCING EMBODIED CARBON, OR CREATING CARBON SINKS, IN THE MATERIALS FROM WHICH NEW UNIVERSITY BUILDINGS ARE CONSTRUCTED?

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Abstract

Traditional construction practices are renowned for being exhaustive in energy, CO_2 – intensive and high in embodied carbon. In particular, the use of steel and concrete frames are renowned for having detrimental effects on the environment in the UK and globally. It is these effects which have prompted targets set by UCL to provide embodied carbon circular economies as well as reduce embodied carbon of superstructures and substructures by 40%. Further, a drive towards zero construction waste to landfill is highly sought after and is pivotal to UCLs sustainability strategy.

This study aims to propose a review of the current opportunities UCL may aim to explore when constructing future university buildings. Timber construction is a proposed solution which aims to replace the traditional methods of construction which are steel and concrete. Timber seeks to act as a 'carbon sink' by inhabiting more CO_2 then how much is distributed which is the opportunity this study aims to follow.

The proposal of concrete recycling aims to address the key goal set by UCL of driving towards zero construction waste to landfill. Both proposed solutions are supported with case studies from across the globe to enable a real-world context to be prove the feasibility of such proposed solutions.

At the heart of all these proposals within the construction process and the realistic implementation of such solutions lies with the project manager and their competencies. Defining and perfecting the client brief is proven to be incremental in driving sustainable processes as the client is reliant on the project manager to facilitate an environment where their needs are satisfied. Further, having a great understanding of stakeholder management and proposing earlier means of engagement with external stakeholders categorically, may ensure a greater chance of success.

There is also an insight into the different methods we can implement as a response to the urban heat island effect. The use of green infrastructure as well as Sustainable drainage systems can assist in cooling temperatures down as well as mitigate flood risks.

This research considers the problems of today's traditional construction methods and aims to propose 'carbon sinks' as a result of implementing greater methods of sustainability. We review current literature on the construction process and how the project manager can play a key role in its development. Overall, this research acknowledges the current literature and projects and contributes to it through providing a case for its use.

1.0 Introduction

1.1 Research background

This report intends to explore the prospects for reducing embodied carbon within the materials from which future university buildings are constructed from at University College London (UCL). Table 1 outlines a selected list of the key goals which aim to reduce embodied carbon thus contributing to UCL's 10-year 'Transforming UCL' programme and UCL Sustainable Building Standard (UCL, 2020; UCL 2019).

Proponent	Key goals
Major projects	• Provide a circular economy statement covering embodied carbon and opportunities to retain existing materials for superstructure and substructure. • Reduce embodied carbon of superstructure and substructure by 40% and/or to <500 $kgCO_2/m^2$ (see RIBA Sustainable Outcomes Guide, modules A, B & C). • BREEAM Excellent or above must be achieved on all new build and major refurbishment projects, with due regard for life cycle value (defined below). • All our construction projects will target zero construction waste to landfill and provide clear documentation to demonstrate how this has been approached and achieved.

Table 1: Key goals set by UCLs Sustainable Building Standard Report (UCL,2019)

This report aims to propose solutions which would successfully assist in the accomplishment of goals set out in table 1 through the proposal of timber construction, recycled aggregates, and other embodied carbon solutions. Reducing embodied carbon is a great opportunity to successfully contribute extensively to goals set out in table 1 as well as; reduce resources and associated costs whilst alleviating longer term risks around resource availability. Further, reducing embodied carbon enables a site which is able to reduce associated negative environmental and social impacts of construction, operation, and maintenance of activities.

Global emissions need to be cut by 7.6% every year for the next decade to meet the 1.5 degrees target set by the United Nations (2019) and the UK government have set a target to be net zero by 2050. In this context, proposing embodied carbon options offers the opportunity to future proof buildings as well as be innovative (UN, 2019) and upgrading the composition of fabrics of current and future buildings further contributes to a reduction in embodied carbon through recycling, prefabrication, and less deliveries to site.

Currently, UCL spends £550m on procurement (Figure 1) which includes construction activities, in turn, contributing substantially to the well known facts that the construction industry is renowned for being the least sustainable industry globally as it accounts for the largest share of both global final energy use (36%) and energy-related CO2 emissions (IEA, 2018).

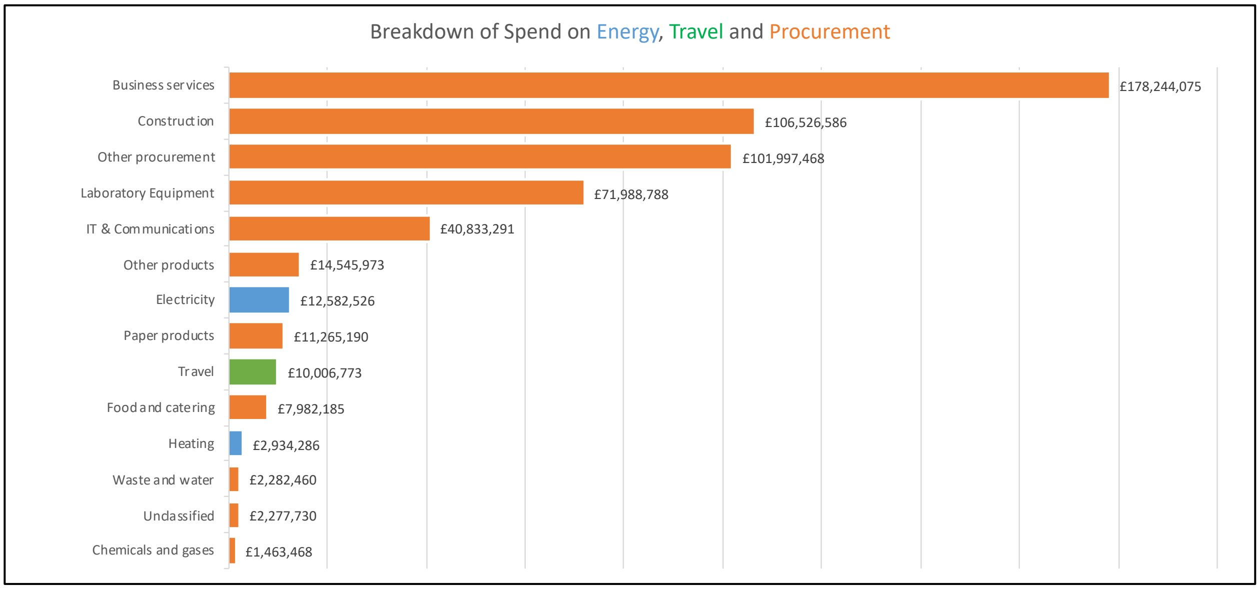

Figure 1: Breakdown of Spend on Energy, Travel and Procurement (UCL, 2021)

Construction is of incremental importance within the built environment and its success is greatly reliant on the methods of how construction professionals impose this synergy within our environment (Strong and Hemphill, 2008). This process is administered by the extensive use of energy within the creation of buildings and infrastructure indirectly when it is in use. The construction industry is resource inefficient and wasteful due to its depletion of over 50% of all raw material which is extracted globally (Ruuska and Hakkinen, 2014). This setting presents a case for the use of more efficient materials such as 'carbon sinks' which can be defined as an area or ecosystem that absorbs more carbon dioxide than it releases (National Geographic, 2020).

1.2 Research problem

Utilising construction materials have a negative impact socioeconomically, environmentally and economically as its use relies on the use of heavy machinery where some processes use fossil fuels and an insufficient use of electricity to burn fossils in turn, partaking in 36% of global energy usage and 40% of CO_2 discharges (IEA, 2019). Figure 2 showcases the great effect several industries and materials contribute to globally and concentrating on the building industry we can analyse (Allwood, 2012):

- 64% of global CO2 emissions are energy-or-process related
- 35% from the industry; 31% from buildings and 27% from transport.
- Steel, cement, and aluminium contribute to 47% of industrial carbon emissions.

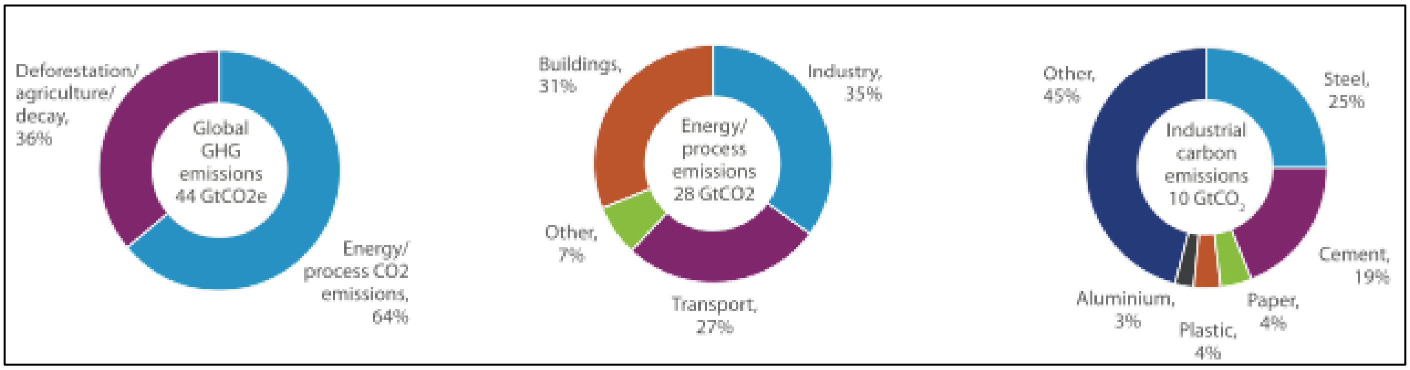

Figure 2: Sources of global CO2 emissions (Sustainable Materials - With Both Eyes Open, 2012)

Such findings places onus on the need for greater resources to be spent on the early stages of the project as this could have a greater impact on energy and pollution being decreased throughout a dwelling's entire existence (Saddul and Opoku, 2021 (forthcoming)). CO_2 in combination with the increase in burning carbon-based fossil fuels has led to greater rates of global warming due to a higher concentration of carbon in the atmosphere. In terms of the UK, the built environment accounts for 45% of the total UK carbon emissions (Met Office, 2021).

The building industry uses more than 400 million tons of material each year (UKGBC, 2018) which contributes to a greater adverse environmental impact. Extracting raw materials, then transporting them to the manufacturing plant and site, the energy consumed associated with this process in combination with waste generation suggests the proponents utilised during the building process are greatly destructive.

It is believed the building industry consumes 40% of the worlds usage in gravel, sand, and raw stones as well as 35% of virgin wood per year (Ametepey and Ansah, 2015). In terms of waste, the UK generated 202.8 million tonnes of waste in 2014 with the construction industry creating 59% of that. Construction generates great amounts of emissions as it relies on fast and cheap solutions which need to be replaced every year (NBS, 2018).

The earths properties and environment are at high-capacity usage due to existing ways buildings are created and maintained. Scarcity of resources coupled with a need to reduce environmental impacts of construction handling suggests there is required prominence on resource efficiency within the sector. This places a greater need for the development of the industry towards the realms of sustainability.

1.2.1 Urban heat island effect

The urban heat island effect (UHI) occurs when cities replace natural land cover with dense concentrations of pavement, buildings and other surfaces which absorb and retain heat. This has a detrimental effect on increased energy costs, illnesses, mortality, and air pollution (EPA, 2021). By 2030, it is estimated 60% of the world's population will be living within urban areas (Arup, 2014). There are four reasons why hot weather poses an increased risk to the people inhabitant in London and other stories (Arup, 2014):

1) Higher average temperatures and more extreme hot weather event are because of climate change.
2) The UHI effect reduces the ability of areas of the city to stay cool or cool down during hot weather.
3) Changing demographic – an ageing population coupled with more under five-year-olds increases the number of potentially vulnerable people.
4) Urban development increasing and densification contributes to the UHI effect as well as puts increasing pressure on existing open green infrastructure thus providing shade and cooling for cities.

These factors contribute to the discomfort of the general population when there is hot weather because as temperatures rise in cities, so does the number of heat related illnesses and emergency call outs. It is understood heat-related stress currently accounts for ≈1,100 premature death and <100,000 hospital patient-days per year (Arup, 2014).

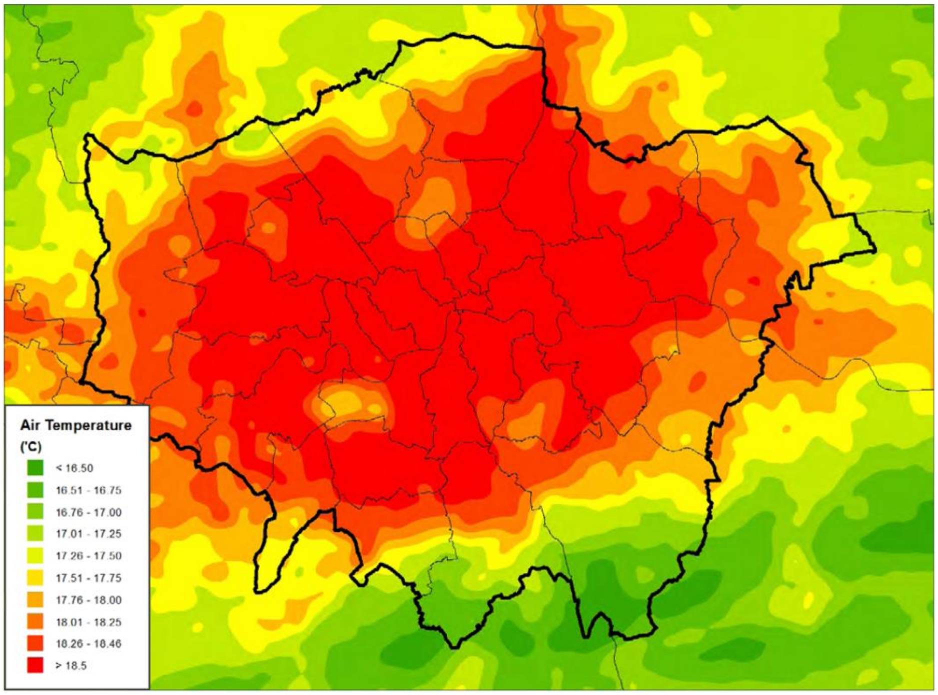

Figure 3: Air temperature across London (Arup, 2014)

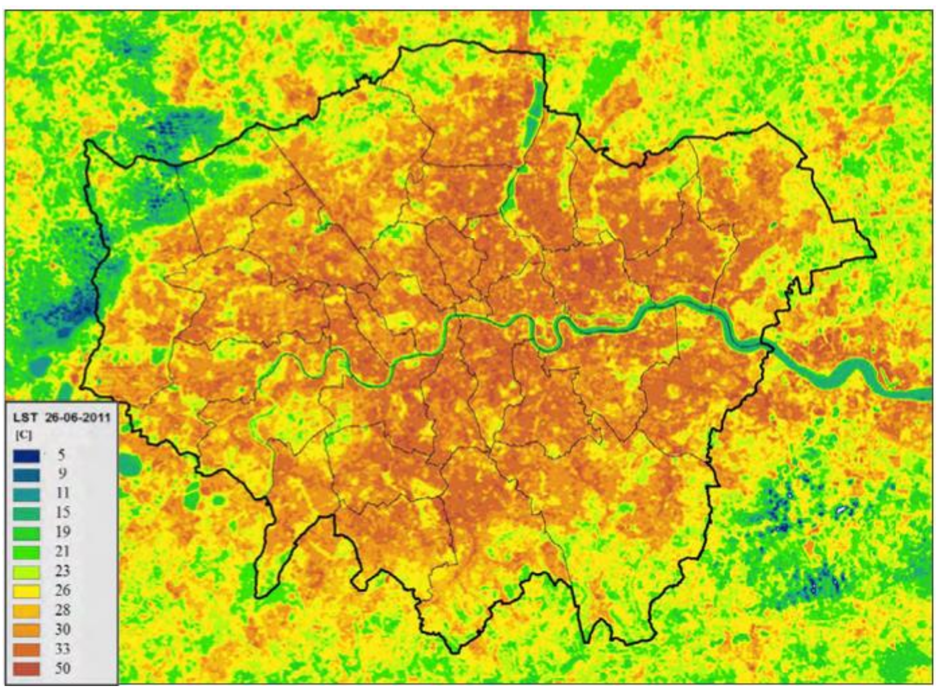

Figure 4: Land surface temperature across London (Arup, 2014)

At city scale (figure 3 and 4), a visualisation which depicts spatial variation of air temperature as well as land surface temperature across the whole of Greater London were produced, and it is suggested there is an immediate indication of high heat risk (Arup, 2014). This image suggests the difference in both temperatures between surrounding counties and London is at a great scale. Moving away from Central London suggests temperatures decrease immensely. Also, the cooler spots can be spotted around large-scale parks and green spaces such as Hyde Park, and Regents Park.

68% of the entire population are expected to live in urban environments by 2050 and with the global demographic trend towards urbanisation there is a greater chance of more isolation and disconnection from nature. In terms of the UK, air quality costs £8.6 to £18.6 million per year through hospital admissions, reduction in life expectancies and heat-related illnesses (UCL, 2018). Outdated buildings coupled with traditional methods of construction has led to seasonal issues including old heating and air-conditioning systems which are less energy efficient than newer models.

The UHI effect negatively effects health of people, biodiversity of land contributes to climate change at a global, regional and local level. This immensely relates to the use of HVAC systems during summer and winter months when temperatures are increasingly extreme and attempting to regulate temperatures requires more system output.

1.3 Research Questions

This report is novel and timely due to the importance of UCL's sustainability strategy which aims to become net zero by 2030. The report therefore addresses the following question:

- What are the prospects for reducing embodied carbon, or creating carbon sinks, in the materials from which new university buildings are constructed?
- How can we address the effects of UHI effect?
- What role can the project manager play in the achievement of a sustainable construction project?

1.4 Aim and objectives

This report explores the alternative methods of construction which can be used as opposed to traditional methods of construction. Specifically, analysing various materials which reduce embodied carbon as well as ones which act as a 'carbon sink'. The specific objectives are:

- Critically examine ‘carbon’ sinks and provide a case for its implementation in future university buildings.
- Understand how organisational structures enable the project manager to drive sustainable practices in a project.

1.5 Structure of the report

Introduction: the introduction aims to present a background and the need for this report by giving a context of the current situation the construction industry is in terms of its effect material usage has on the environment. This is followed by the key research questions and objectives this report seeks to target.

Methodology: this section aims to provide an insight into how research was derived and why the use of secondary data was incremental to the development of the report.

Proposed solution 1: the first solution proposed is the implementation of timber construction, in particular, timber frame construction. Cross-laminated timber (CLT), Nail-laminated timber (NLT) and Laminated-veneer timber (LVL) are three options which are proposed with the use of case studies which seek to apply a real-world context to the theoretical research. We also discuss the use of timber framed windows. All options proposed are renowned for their ‘carbon sink’ properties.

Proposed solution 2: the second solution is the use of recycled aggregates and concrete replacement which aims to exploit the opportunity proposed of reusing carbon-intensive materials instead of creating a new load. This is further supported using case studies which propose radical savings in terms of emissions and deliveries to site.

Project manager role: this section seeks to understand how sustainability can be driven at the front-end stages of the project. This focuses on the project managers role and how they can drive its use as they are an agent of change who work in conjunction with the clients’ needs and the implementation of project goals.

Recommendations: the recommendations section summarises the findings of the report by the proposal of recommendations derived from the case studies and research proposed by the secondary data.

2.0 Methodology

This report is informed by secondary data which is based upon researching ways of embodying carbon within the materials of buildings. The use of case studies enhances the understanding of the technology and enables the reader to apply the knowledge gained into a real-world context.

This report can be likened to a literature review which is a methodical method of assembling and integrating previous research (Baumeister & Leary, 1997). A well-researched review as a research method allows a strong foundation for increasing knowledge and enabling theory development. Connecting findings and viewpoints from a range of empirical findings presents this study with the capability to address the proposed research questions.

The following report seeks to derive research based upon industry published reports and case studies based in the UK and internationally. By taking this approach suggests a systematic review which identifies and critically appraises published research as well as enables a collection and analysis of the data thus permitting informed recommendations (Liberati, et al., 2009) (Baumeister & Leary, 1997)

3.0 Proposed solution: Timber Frames

Recent advances in the technological capabilities of wood in terms of engineered timber and beam-and-post structural frames have presented an opportunity which changes the inferior stigma amongst structural timber. A timber frame consists of panelised floors and structural walls derived from timber studs and board products whereby the frame spreads lateral loads to the foundations. Timber frames present a plethora of advantages in comparison to traditional methods of constructing structural frames:

1) Weight decrease in comparison to concrete or steel structural frames. This is sought after when dealing with complex tunnel situations[1].
2) A sustainable, low-carbon alternative to traditional frames. (Spear et al., 2019)
3) There is a reduction of embodied emissions at approx. 20% and a bigger reduction is seen for CLT structures (60%) (Spear et al., 2019).
4) The level of carbon storage at a building-scale is approx. 50% lighter for timber frame masonry (Spear et al., 2019).
5) Timber offers an offsite construction solution as well as dryness thus making it easily flexible to modularisation and prefabrication.
6) Timber enables a standardised approach of key structural components like floors, columns, and beams. Preferable in large scale commercial buildings.

Chapter 3 aims to explore the benefits of embodying carbon and realising timber construction as a carbon sink by investigating the use of CLT, NLT and LVL which are supported using case studies thus providing a real-world context. There is a plethora of approaches which are deemed appropriate for timber structured buildings.

3.1 Cross Laminated Timber Panels

CLT is a material that is prefabricated in a factory environment from sustainably derived timber. CLT can be manufactured from various woods such as scots pine, douglas fir, larch and mainly spruce (B1M, 2017). The process required for a panel to be made are (B1M, 2017):

1) Once at the factory, the timber is planed (all wood surfaces have been brought to a uniform level and is ready to be worked with) and then kiln-dried to decrease the moisture content.

[1] https://www.bkstructures.co.uk/case-studies/dalston-lane

2) The conditioned timber is then loaded into layers known as lamellas (sheets of wood held adjacent to one another in a gill-shaped structure) on top of each other with every layer being positioned at a 90-degree angle to the one underneath.
3) The lamellas are then glued, using a non-toxic adhesive, and hydraulically pushed together to form a high strength structural panel.

In theory, singular panels can be of any size, but their width is restricted by the size of the manufacturing equipment which tends to be 11 feet wide. Practical purpose panels tend to be 45 feet lengths whereas 75 feet panels have been produced however the length of the panel tends to depend on the method of transportation to site (B1M, 2017). Computer Numerically Controlled joinery machines can create any shape of panel desired thus suggesting window and door openings can be pre-cut through prefabrication thus ensuring panels can be delivered on site.

It is understood the production of CLT components only consumes 50% of the energy that is needed to produce similar concrete with 1% of that needed to produce steel (Hairstans, 2010). Due to its prefabrication advantage, it can be delivered to the site when they are needed thus suggesting the construction methodology is ideal for schemes which have inadequate on-site storage capacity. Once delivered, the panels are lifted into their correct positions using pre-installed lifting straps and are increasingly built thus reducing building cost and time (Woodworks, 2012).

CLT panels are cleaner than traditional methods due to the lower levels of dust that are reduced as well as provides a quieter environment thus providing a greater benefit for projects erected in urban areas (B1M, 2017).

3.1.1 Fire protection

CLT remains structurally stable when exposed to high temperatures unlike unprotect steel. This is due to the outer layer of timber charring and formulating a layer surrounding the structural core thus retaining its load bearing capacity (TRADA, 2013). It is able to resist blazes between 30 minutes to 2 hours liable on its engineering and formation (Greenspec, 2021).

3.1.2 Structural configurations

CLT panels encompass the capability to be used for various applications. CLT panels can be used as a pre-insulated wall as well as roof cassettes (STA, 2015). In the instance of a room-in-the-roof construction is required, CLT panels can be used through a breathable roof underlay and strengthened insulation which would tend to be located above the CLT panels to enable a 'warm roof' construction which can, in fact, be an insulated cassette.

Case Study: Dalston Lane

Dalston Lane is known for being the world's largest cross-laminated timber (CLT) building, standing at ten storeys, the 121-unit development is constructed of CLT from the first floor upwards. Timber was chosen as the best structural material due to various constraints on the project. Constraints such as a planned train route and existing train line ran under the site which created the challenge – unfeasible for the use of a traditional piled foundation as well as a restriction on the amount of weight due to the reserved high speed 2 link (Ravenscroft, 2017). Gavin White, an engineering director from the project discussed how such constraints made CLT an ideal solution: *"CLT buildings, when they are built with all the people and equipment in them, are about 30% lighter than an equivalent steel or concrete frame"* (Ramboll, 2016).

Its lightweight and sustainable approach meant the building erected a further 15 houses to be delivered on site which would not have been realised if traditional structures such as steel or concrete were used. Referencing the structure, the basement level through to the first-floor slab was constructed of concrete and from that point to the top of the structure is timber. There is at least three and a half tonnes of steel above the first-floor deck in the entire building (bkstructures, -).

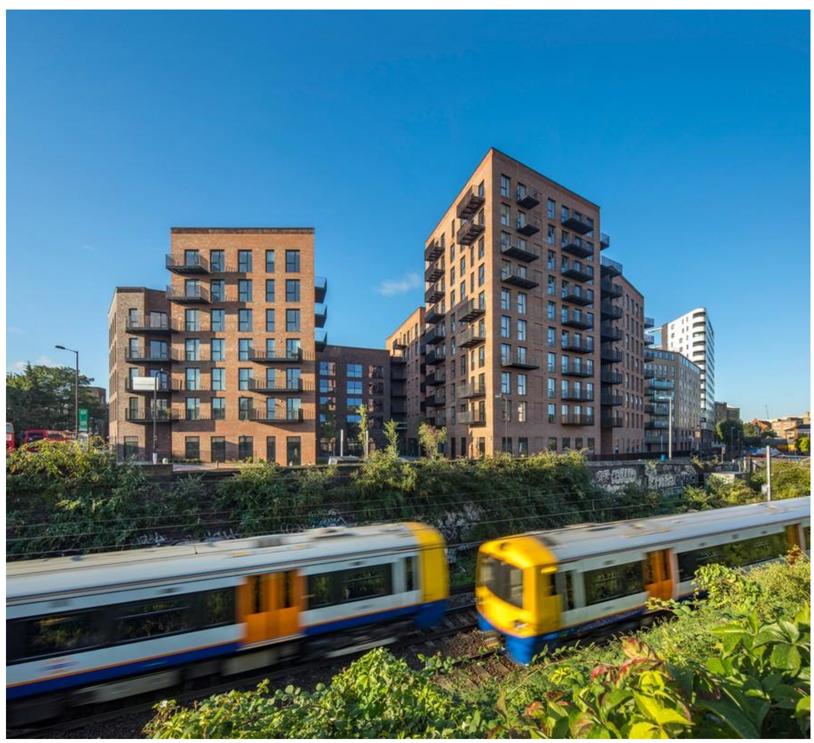

Figure 4: Dalston Lane timber building

4,500 cubic meters of timber were used for Dalston Lane which amounts to 2,300 trees and the building accommodates an estimated 800 people in the building thus averaging 3 trees per person. In terms of deliveries, there were 11 to site which was seen as a greater reduction in comparison to an equivalent – sized building where an estimated 700 deliveries would have been required to build the frame (Ravenscroft, 2017). In terms of the aesthetic, Gavin White said;

"Over the past 15 years of building with the material, we have realised that not only is this material sustainable, replenishable, but this building material also builds buildings beautifully," he says. "It builds them quickly, it builds them inexpensively, it builds them quietly, it builds them with fewer deliveries to site, so it really is in terms of renewing our city, in terms of increasing the density of our urban environments, a fantastic material to work with."

3.2 Nail-laminated Timber

NLT has a reputation for its structural performance and design elegance which creates mesmerising spaces in a range of historical buildings and modern new projects. Applications tend to include flooring, decking, roofing and walls, elevators, and stair shafts. Its pure wood construction is consistent and attractive for aesthetic purposes and its flexibility enables the creation of monolithic slab panels which supports structural and design requirements, which includes cantilevers and curves (Thinkwood, 2021). Further, the incorporation of plywood or oriented strand board sheathing on a face of the panel provided an in-plane shear capacity which enables NLT to be integrated as a structural diagram (structural element which transports loads laterally to the resting elements of a structure) or a shear wall (Think wood, 2021).

3.2.1 Fabrication

The creation of an NLT panel does not necessitate a devoted manufacturing facility in comparison to other timber materials such as CLT which suggests it can be constructed with easily accessible dimensional lumber thus enabling project teams and manufacturers to source local materials (WBDG, 2019).

3.2.2 Design notes

The cross-section depth of NLT panels can be constant or varied and utilising differing sizes of lumber in alternating laminations with the size difference typically kept within 2" to increase structural efficiency (WBDG, 2019). The exposed surface of individual laminations can be fabricated to be smooth or ribbed which is solely dependent on the desired aesthetic.

3.2.3 Carbon Sequestration

NLT panels are constructed of wood thus suggesting they are a ‘carbon sink’ due to its capability in sequestering carbon in solid form thus keeping it from entering the atmosphere as CO_2 (WBDG, 2019).

Case study: T3 Minneapolis Office Building

- Office building, Minneapolis, United States
- Architects: DLR Group, Michael Green Architecture
- Year: 2016
- Contractor: Kraus-Anderson Construction Company

The T3 office building offers a modern interpretation towards constructing a building away from traditional materials. The building offers 224,000 square feet of offices, retail space and there are 3,600 cubic metres of exposed mass timber floor slabs, beams, and columns. All structural components such as beams, columns floors, roof and furniture were constructed of nail laminated and glulam timber. The NLT used was sustainably sourced from trees which were killed by the mountain pine beetle (StructureCraft, 2016).

Using NLT presented the advantage of the building being built at a speed which exceeded conventional steel-framed or concrete buildings. The building witnessed 180,000 square feet of timber framing erected in less than 9.5 weeks. This amounted to 30,000 square feet of floor area installed per week (StructureCraft, 2016).

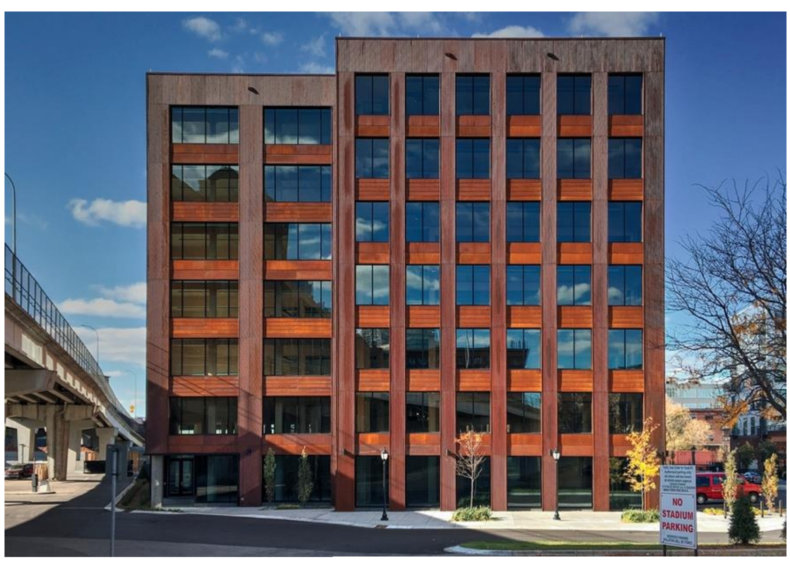

Figure 5: T3 Minneapolis Office Building

The bottom level of the structure is fabricated with concrete and is specially made for retail space and an amenity centre for tenents with the above six storeys built of pure wood offices (StructureCraft, 2016). The decision to use NLT was based on structural, lower costing and faster procurement times.

Using a mass timber system meant the building was 30% lighter than a steel equivalent: 60% lighter than an equivalent concrete building which enabled a smaller foundation and decreased seismic load (StructureCraft, 2016). Extra fireproofing was unnecessary which allowed cost savings. An estimated 3,600 cubic metres of wood was used within the structure thus enabling 3,200 tonnes of carbon being sequestered for the entire life of the building. Over 1,100 8' x 20' NLT panels were used which is the equivalent square footage of nine hockey rinks (Structurecraft, 2016).

3.3 Laminated Veneer Lumber

Laminated veneer lumber is used in various types of construction projects from new buildings to renovation and repair. LVL can be used to construct structural elements such as columns, beams and panels and tend to be used due to their various advantages, proven physical structure performance and flexibility.

An LVL panel is constructed of 3mm thick veneers which are glued together with weather-resistant phenolic adhesive which suggests the final LVL product does not have to be limited to the dimensions of the raw material. Small-diameter logs can be used to produce large LVL panels and beams (FWI, 2020). Engineered wood products tend to be higher in production costs to sawn timber, however LVL can be designed with smaller dimensions for similar construction which would require more timber elements. LVL can also be used for applications where suitable timber sizes are unavailable.

The strength to weight ratio of LVL is renowned for being extremely high as it is renowned for encompassing a lack of sizeable defects. LVL is known to be twice as strong as steel in proportion to weight (FWI, 2020) and due its structure, it is free of warps, splits and splinters as well as being dimensionally stable. Its dry nature means the risk of shrinkage on site is eliminated (FWI, 2020). LVL is produced from traceable, renewable recyclable wood and is from certified sources and is renowned for being a carbon sink as $1m^3$ of LVL encompasses a captured carbon equivalent to 789kg of CO_2, thus making it an environmentally friendly choice (FWI, 2020).

Case Study: Mjostarnet The Tower of Lake Mjose / Voll Arkitekter

Key information

- Location: Brumunddal, Norway
- Architect: Voll Arkitekter
- Year: 2019
- Manufacturers: SFS Group, WoodSafe

Mjostarnet appointed a team who were locally sourced to construct an 18-floor building at a height of 80 to 90 metres in Brumnddal. Constructed from 3,500m^3 of timber (14,000 trees) it was imperative that the timber was sourced from healthy and sustainable forestry. This mixed-use tower consists of 18 storeys with different uses, the official architectural height is said to be 85.4 metres (Archdaily, 2020) with each floor being the size of 640m^2. The entire floor space for the tower is said to be about 10,500m^2 with an additional 4,500m^2 public bath (Archdaily, 2020).

Figure 6: Mjostarnet the tower

There are 5 office storeys as well as a 4-storey hotel which encompasses 72 rooms with floors 12-16 encompassing 33 residential units which have balconies which overlooks the lake. The top two floors are divided into 3 residential units, exhibition room and a viewing terrace encompassed on the 18th and 19th floor (MetsaWood, 2019). The floor elements were prefabricated using LVL and glulam thus ensuring a fast, light, and green material produced in Finland.

The first 10 floors are constructed of prefabricated wooden elements – LVL panels combined with glulam. However, the decks on the upper floors, with apartments are constructed of concrete thus combating the likeliness of the amount of swaying in the building as it increases the higher you are within a wooden constructed building. The use of timber enabled a lighter building which was beneficial in the assembly phase as all the elements were prefabricated and light to handle which enabled the structure to grow by almost a floor every week (MetsaWood, 2019). A solution which Mjostarnet may have implemented to increase the amount of carbon sinks within the building is the use of timber framed windows which we discuss in the next section.

3.4 Timber window frames

Timber window frames are a great alternative to modern uPVC installations Specialist suppliers who are capable of manufacturing timber windows to be carbon negative and are constructed with low or no VOCs and are recyclable at the end of their useful life. A report by Heriot Watt University on timber, modified timber and aluminium-clad timber windows found all the timber-based frames considered had significantly lower impacts than PVC-u equivalents (Menzies, 2013).

The report demonstrated that some timber window frames were carbon-negative over their original life cycle. Across the estimated lifespan of 60 years, each timber window installed was shown to save 160kgs CO2 e which amounts to over one and a half tonnes of CO2 e per average house of 10 windows (Menzies, 2013).

3.5 Limitations

As discussed, timber construction provides a plethora of advantages, but its implementation does come with limitations. A pre-designed timber frame offers savings in programme and speed of construction as well as sustainability however the cost can be much higher due to more price certainty achieved as factory costs are more predictable and fluctuate less (DBW, 2021). Some case studies have outlined that there needs to be a consideration of differential movement factors with tall timber buildings. Further, timber is known for its water retention and when it dries, timber elements can decrease in size. To stabilise a primary-structure timber frame, there may be a permittance for a secondary structure made of concrete which would be integrated with the buildings core (Building, 2019).

3.6 Summary

In response to the current problems associated with high levels of CO_2, UCL can implement timber technology in the form of new university buildings. The case studies suggest its use has a much lower carbon footprint than cement and absorbs CO_2 whilst growing. Sustainable timber usage relies on sustainable forest management and provides an opportunity for the mitigation of global warming effects thus contributing to achieving climate policy objectives.

Specific due diligence systems distinguish wood from various building materials through the verification of the origin of the wood raw material. Further, the European Union Timber regulation was formulated to ensure that all wood placed within the European market is covered by a system for verification of its legal origin. For sustainability to be realised at building level, all timber should be sourced FSC certified as Forest certification schemes provided 3rd party verification which suggests the forest management practices are sustainable. For wood products to be sustainable sourced it must be FSC labelled thus suggesting it includes 70% raw wood material from certified forest (PEFC,-).

Timber frame construction is becoming increasingly popular due to its flexibility and the plethora of readily available options. Carbon sequestration and lower embodied carbon buildings provide the opportunity for UCL to drastically improve their material usage. The three timber construction methods investigated are renowned for their structural rigidity, great tensile and compressive strength as all panels is strength graded to BS EN 14081-1:2005.

4.0 Proposed solution: Concrete replacement

4.1 Recycled/secondary aggregate

Cement is a key material in concrete and is accountable for 2% of UK carbon dioxide emissions (mpa, 2020) and on average has an embodied carbon of an estimated 830kg CO_2e/tonne (mpa, 2020). One cubic metre of concrete needs one tonne of coarse aggregate, 800kg of fines and 320kg of Portland cement however these quantities vary in response to technical and architectural requirements.

Recycling concrete and using secondary aggregates propose a great opportunity in reducing waste, as well as a reduction in the associated environmental costs of exploiting natural resources. Concrete recycling gains are imperative as it protects the use of natural resources as well as eradicates the need for disposal through the use of readily available concrete as an aggregate source for new concrete or other applications. The process of concrete recycling is viewed as simple as it only requires breaking existing concrete and then removing and crushing the material in respect to the specified size and quality.

Recycled concrete contributes to a reduced amount of material being sent to landfill and when concrete becomes an aggregate, any associated metals encompassed within it can be removed and recycled. The space created by recycling suggests it becomes a premium thus reduces the need for its use and reduces the economic impact of the entire project (PCA, 2021). Moreover, environmental impact of concrete aggregates extraction process is reduced which suggests recycled concrete aggregates decreases the need for virgin aggregates. This has a greater effect on the need for transportation and material production needs being minimised.

Recycled concrete aggregates are known as a 'carbon sink' as they have the capacity to absorb a large amount of carbon dioxide from the surrounding environment. Looking at published industry sustainable certifications, LEED Green Building Rating System suggests recycled concrete is recognised in its points system. Credit 4 (Materials and Resources) states, "Specify a minimum of 25% of building materials which contain in aggregate a minimum weighted average of 40% post-industrial recycled content material" (PCA, 2021).

In terms of LEEDs construction waste management – credits can be gained. Credits can be awarded based on saving at least 50% of waste from landfill disposal. Concrete offers a great opportunity in todays need for sustainability. It's a great opportunity as it can be adapted to the current needs of the industry and the world.

4.2 Ground Granulated Blast Furnace Slag

Ground Granulated Blast Furnance Slag (GGBS) is renowned as a cement substitute and is created from a by-product of the iron-making industry. Companies can enable one tonne of concrete which incorporates GGBS contribute to a reduction of the embodied CO_2 by an estimated 900kg when compared against the use of one tonne of Portland cement (Hanson, 2021).

In the UK, GGBS tends to be available as a separate material for concrete and is added during the concrete mixing process. It can replace up to 70% or more of Portland cement (Rashad and Sadek, 2017); Hanson, 2021). In terms of the British Standards, GGBS is known as an 'addition' thus counting towards the content of cement in concrete (Hanson,2021). In so doing, suppliers conform to BS EN 15167-1 as GGBS can be used within mortar, concrete and grout and is available within the UK.

Case Study: UCL Marshgate 1

A life-cycle assessment of UCL's Marshgate 1 found the use of reinforced concrete was the largest source of embodied carbon; the concrete contributed 45% of the embodied carbon total, of which 23% and 22% arise from the superstructure and substructure respectively. The proposed use of 75% GGBS concrete replacement within the substructure concrete mixes reduced the reinforced concrete contribution from 45% to 37% of the total embodied carbon which is equivalent to 60kgCO2e/m2, or 2400 tonnes of embodied carbon (Arup, 2019).

Case Study: London 2012 Olympic Stadium

The London 2012 Olympic Stadium provides a great case study for embodied carbon savings which were achieved through utilising concrete with 100% recycled aggregate as well as surplus steel from a local gas pipeline. 500,000 cubic metres of ready-mix concrete were estimated to be used for the building of the park through building both sporting venues and infrastructure. This required aggregate requirements of an estimated one million tonnes.

Achievements

1) The Olympic Delivery Authority found the initial estimate of 500,000 cubic metres to be extant in terms of environmental impact which led to the actual volume poured being an estimated 400,000 cubic metres with a further 20,000 cubic metres precast off-site.

2) Design solutions have led to a 11% decrease in concrete volume used and the entire saving delivered was 20,000 tonnes of CO_2 as well as only the use of 120,000 tonnes of primary aggregate use (ODA, 2011).
3) The ready-mix supplier used achieved a 2.2% reduction within the carbon footprint of the concrete used against the renowned UK average thus saving a total 2,500 tonnes of CO_2 through the selection of an energy efficient cement supplier (ODA, 2011).

Overall, due to the recycled use of aggregates, there was a carbon saving of 6,200 tonnes, which amounted to a reduction of 5.1% in terms of carbon footprint. Further, greater than 70,000 heavy vehicle movements were eliminated from the motorways and local roads (ODA, 2011). In summary, the Olympic stadium provides a great example of using recycled concrete aggregates on a large scale which suggests its feasibility would be suitable for use in a university setting.

4.3 Limitations

There are two types of cement paste within recycled aggregate concrete: 'new' paste which creates the strength of the concrete and the second type is an 'old' paste where its composition, water/cement ratio and degree of carbonisation are unknown (BFT International, 2013). Both types of recycled aggregates may inhabit unknown compounds which may initiate dangerous chemical reactions. Further, it is known that recycled aggregates can increase porosity, thus enabling the transportation of moisture which is required for all types of reactions (BFT International, 2013). This presents more difficulties when it comes to enabling a durable concrete exact to the required specification.

Consideration must be made when using recycled concrete as it has a lesser durability which may require a mixture of special materials like fly ash to improve its durability (Thomas, 2007). Further, there tends to be a mixture of compressive strengths per batch which suggests recycled concrete aggregate is a material efficient resource which is able to be used in the production of varied-strength structural concrete subject to tests in strength and durability (Chiu, 2006).

4.3 Summary

Recycling concrete through using recyclable aggregates influences transportation costs, environmental impacts, land use and life expectations. Figure 3 displays the great number of environmental benefits the use of recycled concrete can contribute to the building environment which suggests the opportunities that are missed by using traditional methods outweigh the reasons for its use. Concrete is flexible and adaptable and in the event of a redundant structure it provides the opportunity to be striped back to its core and then reused according to new contemporary specifications. In the event of a demolished building this enables a potentially rich source of recycled aggregate for several applications.

Comparing environmental benefits

Environmental issue	Measured as	Impact	
		One tonne of Regen	One tonne of Portland cement
Climate change	CO_2 equivalent	0.07 tonnes	0.95 tonnes
Energy use	Primary energy	1,300 MJ	5,000 MJ
Mineral extraction	Weight quarried	0	1.5 tonnes
Waste disposal	Weight to tip	1 tonne saved	0.02 tonnes

Figure 7: Comparison of environmental benefits of Regen and Portland cement (Hanson, 2021)

4.0 Reducing the urban heat island effect

4.1 Green roof

Green roofs provide an ideal opportunity for a heat island reduction strategy as they provide both direct and ambient cooling effects (EPA, 2021). They are also renowned for improving the air quality of surrounding areas by reducing the heat island effect and absorbing pollutants (EPA, 2021). Specifically, the opportunity lies within flat roof structures which are an inefficient method of construction which has caused various environmental problems for effecting the flow of energy and material through urban ecosystems.

Figure 8: DakPark in Rotterdam

Flat roofs – small to large and flat to inclined enable a greater possibility for the application of green roofs (C40 Cities, 2017). Green roofs provide a feasible development opportunity as roof surfaces contain 20-25% of total urban areas which provides the possibility of decreasing air and surface temperature of store water and urban surfaces (Akbari et al., 2003).

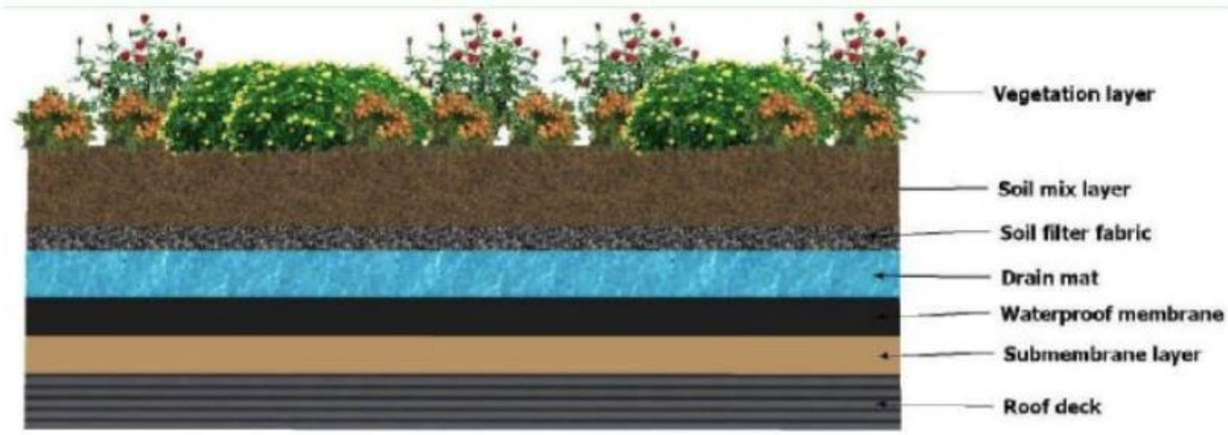

Figure 9: Typical cross-section of a green roof (Shishagar, 2013)

Green roof systems are fabricated of living vegetation which is planted on roofs and permit the capacity to reduce the renowned negative impacts of buildings within the local environment. A typical green roof would be constructed of five constituents from the bottom to the top: a roof support, a roofing membrane, isolation, a drainage layer, a growing media and vegetation (Fiigure 9) (Ouldboukhitine et al., 2011). They are also available in 3 different types which are intensive, semi-intensive and extensive. The plant species utilised is a client decision however green roofs have the capacity to lower temperatures because of its direct coverage of plants and as stomata opens this enable's transpiration during the daytime (Blanusa et al., 2013; Santamouris, 2012).

A great benefit of a green roof is the fact that the daily maximum temperature on vegetated rooftops is reduced as well dampens diurnal temperature fluctuations (Santamouris, 2012). In terms of managing runoff quantity, the growing medium and drainage layer of a green roof greatly influence the water retention capacity and runoff dynamics (Banting et al., 2005). Green roofs can retain all small rain events that are less than 10mm and reduces rainfall from 4.3mm/h to an average runoff rate of 2.4mm/h thus suggesting green roofs have the capacity to reduce peak rainfall events (DeNardo et al., 2005).

Extensive green roofs have shown a water holding capacity increase of 17% to 67% over a 5-year period (Getter et al., 2007). In comparison, average runoff retention has been found to be between 65.7% and 75% on an extensive green roof (Mentens et al., 2006). This suggests both varieties present an ideal option for managing stormwater due to its water retention capabilities, postponing runoff until after peak rainfall and cycling precipitation within the atmosphere through evapotranspiration (Moran et al., 2005; Mentens et al., 2006).

Generally, managing runoff is essential within the context of reducing the risk of flooding as it retains 40-100% of rainwater it receives (Whittinghill, 2012). It is also viewed as a 'carbon sink' for nitrogen, lead and zinc and the flexibility of increasing vegetation density suggests a greater probability of increased pollution removal (Gregoire and Clausen, 2011; Francis et al., 2017).

4.2 Green walls

The use of green walls within the design of indoor and outdoor structures provides similar benefits as a green roof in terms of providing thermal mass and a reduction in the urban heat island effect (Dede et al., 2021). It also possesses the ability to absorb noise pollution from local roads and enable improved air quality (Susca et al., 2011).

Figure 10: The Rubens at the Palace in London

The prospect of green infrastructure presents an environmentally friendly solution as its flexibility enables it to be integrated in several ways thus increasing amenity value if it is used recreationally. Reducing flow of water and increasing biodiversity whilst reducing overheating suggests both options are a suitable route for exploitation.

4.3 Water storage

Water storage methods can be installed at or beneath the surface and have the purpose of enabling water to be stored in tanks on the property for water treatment and enables water reuse. A green roof and permeable surfacing can enable rainwater to be collected and released slowly into the ground once heavy rain or a storm has occurred thus allowing natural drainage. This reduces effects of the urban heat island effect such as flooding as water is retained and slowly drains away instead of overwhelming drainage systems.

4.4 Rainwater harvesting

Rainwater harvesting is a reusable rainwater mechanism which enables the collection of water from roofs for use on site. Water gets collected in a tank below or above ground and undergoes a treatment which makes it useable within toilet flushing, irrigation, and gardening. Its flexible nature enables it to be used within domestic, industrial, and commercial settings (TFH, 2021).

The most common type of SuDS tends to be water butts which are a rainwater mechanism and can be integrated at property level. It provides a source of controlling rainwater whilst reducing the properties water usage. Rainwater is collected and its connection to the properties down pipe, an overflow is required to prevent the water butt from flooding thus enabling free capacity for the next storm event (Newsground, 2018). This system is disconnected from the combined sewer and instead, connects a perforated house which incrementally releases storm water into the ground once a storm event has occurred.

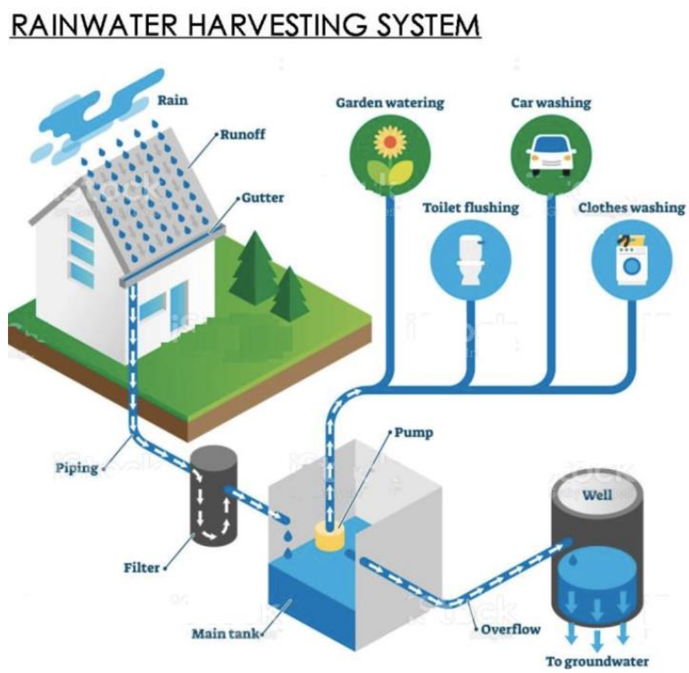

Figure 11: Rainwater Harvesting

This mechanism presents a great opportunity in terms of mitigating potential floods and its easy-to-maintain system enables a reduction within water bills as families can reuse harvested water rather than use a new supply.

4.5 Infiltration Systems

Another water storage technique and green infrastructure are infiltration systems which collect and store water runoff. It processes water through a removal of pollutants which are filtered through blankets, trenches and basins which are constructed from permeable material. Trees are seen as an infiltration system which encompasses the capacity to clean water due to roots encompassing the ability to suck pollutants in. Creating a functional and integrated system, we suggest the use of filter strips and drains.

Using filter strips involves forms of deep vegetation to be planted and used alongside swales. Swales are ditches which are planted and enable water to run through the filter strip first enabling it to be cleansed before reaching a pond. The swales base is constructed of a geomembrane which allows it to reduce density of pollutants and remove fine sediments (Environment Agency, 2012). When surplus rainfall occurs, the swale fills up with water thus contributing to the prevention of flooding and thus enabling the water to runoff into the ground rather than drains.

All options proposed present methods of water retention as well as habitat creation for wildlife and due to its flexibility, can be integrated throughout the city of London.

Case Study: Green roof in Xativa, Spain

A green roof was installed at the Gozalbes Vera Public School located within the city centre Xativa and the extensive green roof consisted of increments of clay bricks which advanced its drainage capacity (Charlesworth et al., 2017). The monitoring period of the roof found 52-100% volumetric efficiencies with figure 12 outlining the hydraulic performance of both roofs conducted in April 2013.

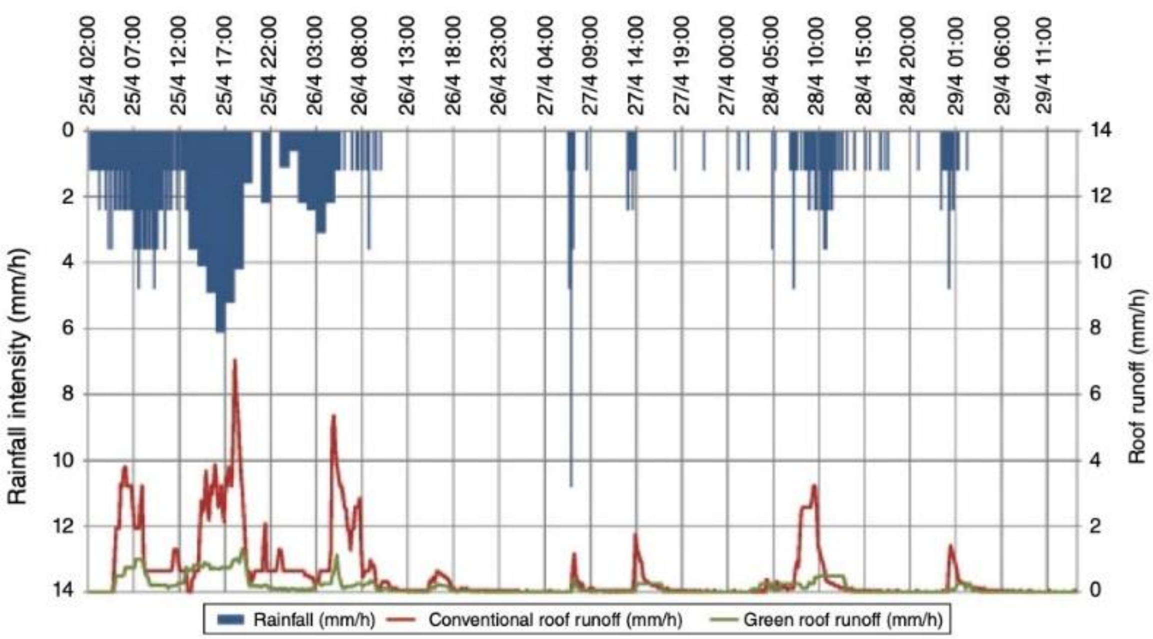

Figure 12: Hydraulic performance during the 25th-29th April 2013 rainfaill event (Charlesworth et al., 2017)

The rainfall volume in its entirety measured at 88mm with the greatest intensity experienced in 10 minutes was 11mm/h which witnessed 31% rainfall volume stored on the conventional roof in comparison to 80% proficiency within the green roof. Findings also derived peak flow reduction was 4-5 times lesser for the green roof in comparison to the cobbled roof.

Case Study: Infiltration basins, Benaguasil, Spain

A topographically elevated area based in Benaguasil, Costa Ermita Park has integrated 3 vegetated basins which were installed to lessen surface water runoff originating from the hill. Its use seeks to decrease the amount of runoff that streams down the streets, producing flooding destruction towards the lower part of Benaguasil (Charlesworth et al., 2017).

Figure 13: Costa Ermita Park before (left) and after (right) retrofitting three infiltration basins

To stop runoff entering the park an old wall was destructed and footpaths were raised to guide water towards the infiltration basins. The greater basins enabled runoff to be sieved through the topsoil and placed within a gravel layer before embedding within the ground through the guidance of pipes into the third basin which integrated a buried geocellular tank. The exceed water flow is then transported through an overflow pipe located within the lowest infiltration basin and through to the community combined sewer.

The storage capacity of these basins is approximately 22m^3 and it is estimated they will eradicate an estimated amount of 1400m^3 of water per year. Of the 19 rainfall occasions that were registered within Benaguasil (Oct 2012 to Sept 2013), only one infiltration basin formed surplus within the combined sewer. The catchment area is measured at 11,250m^2 and highlights the efficacy of water storage in terms of eliminating runoff and sediments from the sewer system.

5.0 Project Management role in driving sustainability in construction projects

Projects and their management can be seen as 'a way to sustainability' and its integration within project management influences the specification of project deliverables or output (Marcelino-sadaba et al., 2015). Project deliverables are discovered within the front-end stage of the construction project and encompass the clients' needs and wants and requires the project manager to outline the methods of achieving those goals. Typically, this would be outlined in the client brief which is derived during the inception and feasibility stage (Figure 14). A key resource is the project manager (CIOB, 2010) and sustainability is becoming a concern within all project management sub-processes (PMI, 2010). Vital project results are the result of environmental project management practices which enables; easier admittance to capital markets, higher customer loyalty, developments within the supply chain and capabilities (Michaelides et al., 2016).

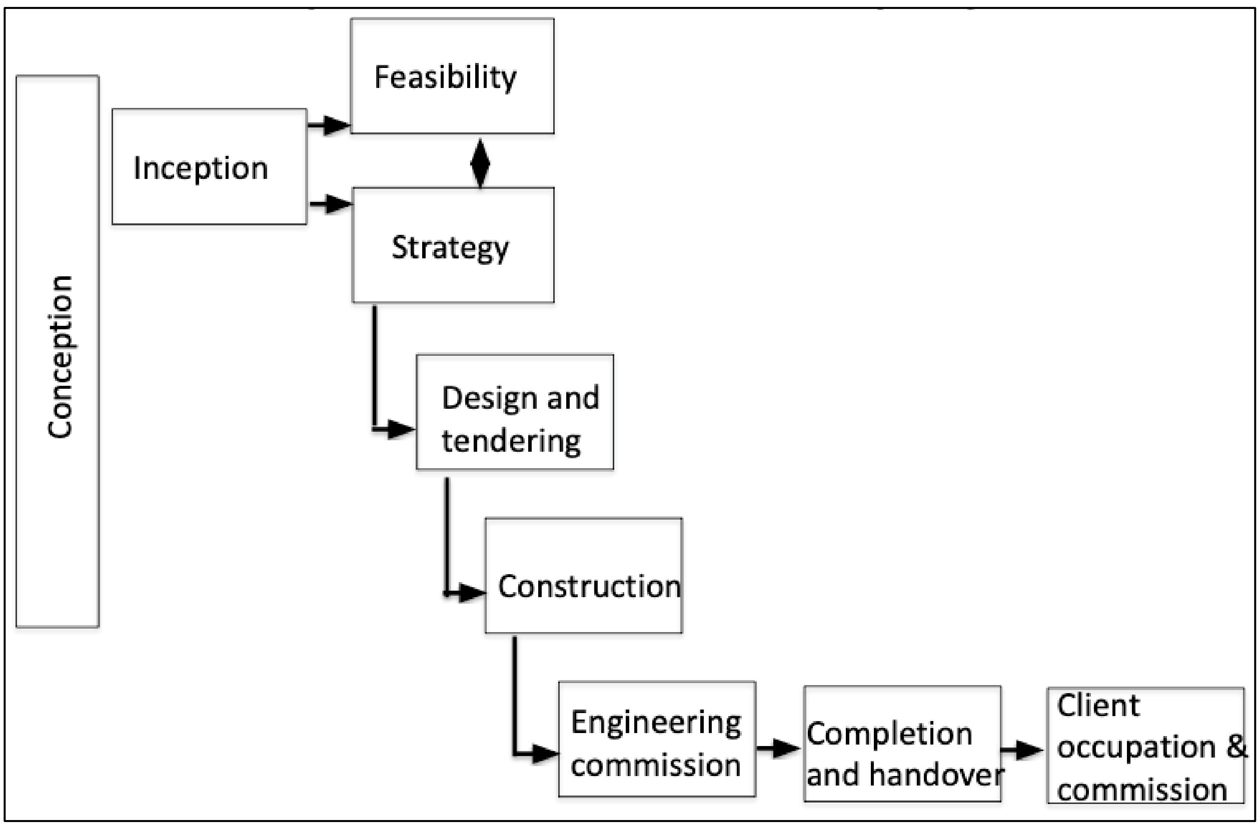

Figure 14: Life cycle of construction projects (CIOB, 2010)

5.1 Satisfying internal stakeholders

Focusing on key competences required of a project manager, communication and decision-making followed by problem-solving, leadership and teamwork have been seen to be the most important competences (Goedknegt and Silvius, 2012; Opoku and Saddul, 2021 (forthcoming)). When managing stakeholders, communication amongst stakeholder management was seen to be an important competency because to drive sustainable construction practices the client or investor must have an awareness and be exposed to the advantages and disadvantages of sustainable technologies (Opoku and Saddul, 2021 (Forthcoming)). Project managers operate within a business which has the intention of being present in an industry which produces profit and in order to give the best opportunity of this the front-end stage must be perfected within a sustainable context.

5.2 Satisfying external stakeholders

It is imperative the project manager promoted a constant consultation at the front-end of the project with external stakeholders such as non-governmental bodies. As a project is renowned for being a temporary endeavour which is key to a unique product, or result, suggests project managers working on construction projects are required to understand various external stakeholders. Having the capacity to adhere to external stakeholders' needs is a form of risk management as is if there is a problem this could affect the progression of the project long-term (Opokue and Saddul, 2021 (Forthcoming)).

5.3 Perfecting the client brief

To propose sustainable practice such as timber construction and recycled concrete a project manager must drive its uptake during the inception stage. Establishing specific sustainable goals within the front-end of the project, perfecting the inception and feasibility stages suggests an understanding of the value and performance of implementing realistic sustainable practices. It is incremental these stages are clearly understood amongst the project team as it is during these stages where the project mandate is delivered, business case is signed off and the project brief is feasible. Traditional project delivery is renowned for being inefficient due to such stages not being fully satisfied in terms of the number of resources dedicated to them. The sequential manner of a traditional procurement process is fragmented as each stage is composed of isolated professionals which further leads to problems during the construction phase such as 'poor' performance for the client and rework (Nawi et al., 2014a; Jha et al., 2004).

5.4 Summary

The temporary character of projects can be viewed to contradict the long-term orientation of sustainability but, projects assist organisations in realising long-term investment goals. Project managers focus on growing an idea to an implemented project which suggests a long-term view of potential issues is not considered whilst the product is being manufactured, used and disposed of. This places greater onus on the project manager to take an extensive view of their role thus implying they take accountability for the results of the project including the sustainability aspects of the final product. Once the developed product or service is achieved it does not disappear, it has a continued impact on the world, a useful period of operation and ultimate disposal.

6.0 Recommendations

Investment-led growth coupled with alignment with market trends such as driving towards the implementation of decreasing embodied carbon within materials can pose the best possibility of improving UCLs approach to future university buildings. This report has provided a comprehensive review of the current opportunities readily available to UCL if they are to achieve the sustainability goals set out. We propose these recommendations which integrate transformative principles within the traditional delivery of projects and are based upon investment in new capabilities at firm level and project level.

6.1 Timber construction

Timber construction provides a flexible solution to the construction of buildings due to the varied options available. The proposal of CLT, NLT and LVL all propose unique qualities which suggests it is up to the client what they would prefer. Although its use is renowned for its positive environmental impacts it offers various aesthetic and structural benefits. Further, UCL may benefit from the fact a timber frame can be erected very quickly dependent on the capabilities of the personnel due to the increased demand for space amongst UCL.

The use of prefabrication permits greater environmental benefits as the wood can be worked in a controlled environment and there is an allowance of faster erection on site. Also, recycled elements of timber can be used but its use does not come without its limitations. Further investigation into the case studies would provide a greater understanding of how limitations were conquered.

6.2 Recycled concrete

Recycling concrete is a process which can be exploited in the future of new university buildings as it is cheaper and a much more environmentally friendly process. There is a plethora of ways it can be used and includes various benefits such as;

- Conservation of natural resources and recycling one tonne of cement can save 1,360 gallons water, 900kg of CO_2 (Bothra et al., 2020).
- Reduction in pollution from transport to landfill.
- Reduces costs of material and waste transportation (CEF, 2013).

Recycled concrete presents a great opportunity for mitigating embodied carbon, saving water, minimising waste, and decreasing the overall cost of construction. However, precaution must be taken as some recycled concrete can be less strong as well as durable than concrete which is derived from natural aggregates.

6.3 Sustainable Project Management

It is important a project manager who has great experience in timber-framed construction or has a sensitive outlook to the incorporation of sustainable principles is appointed within the early stages of the construction process. This is imperative as they have the capability to encourage the project team at an early stage what are the clients' key requirements and how they can positively impact these objectives using sustainable practices. Further, a goal of the project manager is constant communication with the client to drive them to be aware of the benefit of these concepts. A project manager who has a competence in stakeholder management is incremental to the continued growth of the project. This is important within the context of UCL who are based in London. Constructing buildings within London suggests operating in an urban environment which inhabits various stakeholders such as non-governmental bodies, pedestrians, and local workers. Providing specific ways of engagement within the early stages of the project through to completion enables a constant understanding of how the project can be more sustainable. These processes need to be incorporated within the project front-end for the realisation of processes set out in 6.1 and 6.2.

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