Measuring Mass Timber

Deriving a mass timber whole life carbon & quality of life method by evaluating five mass timber UK buildings

QUALITY OF LIFE FOUNDATION

Edinburgh Napier UNIVERSITY

BUILT BY NATURE

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The following individuals were consulted at intervals to inform the research project method and analysis. We thank them for their time and contributions.

Alexia Laird, Landsec
Andrew Lawrence, Arup
Charlie Law, TDUK
Prof. Fionn Stevenson
Dr Jane Anderson
Jess Hrivnak, RIBA
Nathan Wheatley, Engenuiti
Dr Paul Hanna, Hoare Lea
Teemu Hirvilammi, Tampere University, Finland

Participating case study teams:
We additionally thank the project participants and wider stakeholder network. They do not necessarily endorse the entirety of the report.

Architype - Christian Dimbleby, Sebastian Laan Lomas
Fereday Pollard Architects - Jan Kroes
Marks Barfield Architects - Julia Barfield & Darcy Arnold-Jones
Tikari Works - Ty Tikari
Waugh Thistleton Architects - Alastair Ogle, Thor Winkler & Josephine Waugh

Wider stakeholder network:
ASBP
British Land
The Building Performance Network
The Central Cambridge Mosque
Flora Samuel
Fionn Stevenson
MTR Elizabeth Line
Network Rail
TDUK
Storeys
Sutton Harris Academy

And of course our main funder, Built by Nature.

Revision 02
March 2025

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Edinburgh Napier University

Funded by:

Built by Nature

Supported by:

Timber Development UK

ASBP The Alliance for Sustainable Building Products

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Measuring Mass Timber

Executive summary

This report is the primary outcome of the Measuring Mass Timber research project. The study was led by dRMM, with collaborating partners Edinburgh Napier University and the Quality of Life Foundation. The project was awarded funding by Built by Nature in 2022 and completed in 2024.

The aim

The project **develops a methodology for measuring whole life carbon and quality of life of mass timber buildings** that is reasonably replicable and scalable in terms of scope and cost. This method would overall give an impression of the **'whole life value'** of mass timber buildings. Applying the method to five case studies allowed us to provide a limited dataset for real-world mass timber buildings, demonstrating how the method can produce insights that are engaging and relevant. We used our real-world application of the method to refine our recommendations for its adoption. We have identified from all this industry barriers in both the effective utilisation of mass timber and in applying building performance evaluations more widely. We have **started to build a dataset** that is comparable and consistently applied across a range of building types and locations in the UK. This can be added to in the future with wider adoption of this approach.

Key takeaways

1. **Mass timber offers a decarbonisation solution *now*.** All case studies report significantly lower emissions than 'business as usual'.
2. **Quality of life enhancements have been observed. Particularly exciting is the perception of enhanced connection with nature,** although more data will help to build this evidence base to be more representative and wide-reaching.
3. **Biogenic storage potential is significant in mass timber buildings.** The case studies store carbon equivalent to more than fifty thousand journeys from London to Glasgow in the average UK car[01].
4. **BPE/WLC methods are not at present consistently applied, nor conducted widely enough in industry.** Best practice, including for biogenic carbon, should be adhered to.
5. **Mass timber, whilst providing benefits, is not a standalone solution for decarbonisation and quality of life.** Whole life thinking (in every sense) is needed to ensure maximum impact is created from mass timber alongside wider best practice.

OVERVIEW

Case study findings

We evaluated an infrastructure building, a school, a housing scheme, a religious building and a commercial office - buildings where people spend significant amounts of their lives. Across whole life carbon and quality of life all five performed well overall, with the following headline takeaways:

WHOLE LIFE CARBON

Upfront carbon
(A1-5)
Not deducting biogenic carbon
where benchmarks are available

47% below 'business as usual' (LETI band E)

Embodied carbon
(A-C excl B6 & B7) Including deduction of biogenic carbon
where benchmarks are available

Energy Use Intensity
where benchmarks are available

Average < 50% of 'business as usual' (LETI band E).

Upfront biogenic carbon storage
(A1-5)

Total of 5,158tCO2e across the five buildings

QUALITY OF LIFE

Healthy building
Humidity, temp, carbon dioxide and tVOCs as monitored

Internal conditions are generally within recommended ranges

Occupant satisfaction

Occupants feel more relaxed and comfortable

Materials and nature

76% of people are reminded of the natural world by the materials

Main recommendations

- Mass timber has been observed to **support an enhanced quality of life**, in making building users more relaxed and comfortable than other buildings they have experienced. More research into this area would help to develop wider perspectives on the ways biobased materials support quality of life.
- Mass timber has been observed to **support an enhanced connection to nature**, predominantly as a result of the biophilic nature of the wood. Consideration of maximising this impact in designing mass timber buildings can help to support enhanced quality of life.
- Encapsulation of timber structures will likely limit the quality of life benefits of biophilic design we have observed. Building designs should be developed to both **mitigate fire risks and maximise quality of life** potential for occupants in careful balance.
- **Mass timber structures can offer a decarbonisation solution now**. Accelerating the effective use of mass timber (derived from sustainable forestry) should be seen as one readily available part of the decarbonisation effort, especially as whole life carbon likely becomes regulated. Policies (e.g. Part Z) incentivising low embodied carbon will likely increase mass timber use.
- Mass timber should not be seen as solely a solution for upfront carbon reductions. **We need to think holistically over a building's whole life.** Impacts should be considered across other material choices, alongside considering energy and water use. Increasing biobased insulation can increase carbon storage, improve quality of life and reduce energy consumption.
- **Biogenic storage potential is significant.** More work is needed to refine carbon accounting methods that appreciate this without inadvertently incentivising inefficient use of mass timber. Maximising biogenic carbon storage in mass timber structures over long time frames requires being aware of limiting factors and risks upfront. Well loved buildings that support quality of life may be more likely to have extended carbon storage potential. This can be a win-win synergy.
- Mass timber buildings have been observed to **provide healthy internal conditions** against benchmarks. More should be done to monitor this in a wider range of buildings and build this evidence base.
- Beyond mass timber structures, other elements such as insulation, cladding and finishes all offer **additional opportunities for incorporating biobased materials** for both decarbonisation and quality of life enhancement.

Limitations/challenges:

This is a limited cohort of five case study buildings. To be more representative and conclusive in our recommendations, we would like to upscale this dataset in the future to include a wider range of case study buildings.

There were barriers to implementation of the ideal methodology across all aspects of the study. We have sought to develop a method that is viable for mass utilisation as well as balanced in its affordability, time to pursue with rigour, in line with industry best practice.

Additional recommendations when conducting similar analysis:

- It is important to appraise the impacts of buildings beyond carbon. Considering quality of life in conjunction is of merit, carrying potential for strong narratives that are engaging and personal.
- Industry should adhere to WLC best practice methodology for biogenic carbon and end-of-life included. Refrain from using terminologies like 'carbon negative', 'carbon positive' etc. to describe biobased material systems - this is unlikely to be possible under current UK methodologies.
- We would encourage others to engage in undertaking WLC assessments and BPE on their projects, following industry best practice methods (as consolidated and bridged by this report's outlined method) to build further an evidence base. We have demonstrated the potential to apply this method across a range of typologies, building scales and stakeholder types.
- This work is challenging, but rewarding. Expect things to take longer than you might think - allow 18-24 months for a BPE cycle (allowing time for onboarding stakeholders, 12 months minimum for internal condition monitoring/utility data collation and time for review and analysis of data).
- If embarking on similar research, consider carefully finding appropriate monitoring devices for conducting internal condition monitoring. Continually-connected monitoring is best. Consider upfront costs alongside the costs of repeated visits.
- Industry should consider standardising further representation methods (charts, benchmarks etc.) for wider holistic sustainability metrics to help form an understanding of what 'good' is beyond carbon/energy use.
- Some of the most rewarding findings are to be found via the open-ended responses from building users. It is important to include people from a range of backgrounds. Safeguarding and ethics are vital to consider in planning undertaking this work.

Conclusion

- We have developed a method, derived from industry best practice, for assessing quality of life and whole life carbon in conjunction. With this, **we can appraise a holistic impression of the 'whole life value' mass timber offers**.
- From applying this method to a limited cohort of five mass timber case study buildings we **have observed positive impacts of mass timber in both aspects (carbon and quality of life)**. We see potential for wider utilisation of well-designed mass timber buildings to support decarbonisation and to enhance quality of life.
- **More research is encouraged** to better understand the potential and limitations of mass timber in these, and other, aspects.

Figure 1. Quality of Life illustration (QoLF)

Report wayfinding

Report outcomes

The report is structured as follows:

1. **Introduction**

We cover the wider context and how mass timber is hypothesised to offer a solution to supporting decarbonisation and enhanced quality of life. We address why this study was needed.

2. Methodology

We explain the methodological context, how we have applied existing and new approaches and what challenges we have found in the process of applying these on this study in studying carbon and mass timber in conjunction.

3. Case studies

Here we detail the main results from the combined methodology for all five case study buildings. We use these to discuss wider industry challenges and suggest areas for further exploration in scaling up this work in the future.

4. Conclusions

We reflect on the study's outcomes and summarise how we have addressed the main hypotheses.

5. Appendix

This section contains the report glossary, list of key abbreviations, references and list of figures.

Document key

We are mindful that not everyone will have time to read this report from cover to cover. We have developed a set of visual summaries and prompts to help with navigating the content. A key for these is shown below:

Key takeaways

Findings are summarised within the document for ease of use, where complex topics are to be further explored in the main body of text.

To be explored further

This research project has of course touched upon wider issues and identified areas that would make for interesting further analysis and exploration. However, it has not always been possible for us to do this within the confines of this research project. Where this is identified in the report, you will find this highlighted visually in boxes as shown here. We have collated a full list of these wider issues at the end of the report in conclusions.

Definitions

Throughout this report, definitions for key concepts/terms are featured in boxes like this. A full glossary can be found at the end of the report.

Introduction

1

Study overview

Our intention for this project was to develop a methodology for measuring whole life carbon and quality of life of mass timber buildings. We sought to combine and build upon existing industry best practice. We then applied our combined method in assessing five UK mass timber buildings. Our intention is to build an evidence base for mass timber's carbon and quality of life impacts that can be added to by others.

The intention in making methodology recommendations, findings and experiences in conducting this study available to others is that this can make it easier for others to conduct similar studies. We hope through this to trigger a greater availability of comparable data. This evidence base and appreciation of mass timber's potential is a needed drive towards broader adoption of mass timber in the UK.

We see this study as a first step in building an evidence-driven case for timber construction using whole life carbon and wellbeing metrics in combination, supporting DEFRA's goal of 'improving data on timber and whole life carbon'. [02] We seek to determine a more holistic whole life "value".

Primary research hypotheses

1. **Mass timber buildings offer the potential to support decarbonisation** and this can be evidenced through built case studies of a range of typologies as compared to industry benchmarks.

2. **Mass timber buildings contribute to quality of life** and this can be evidenced through quantitative and qualitative evaluation of peoples' experiences in inhabiting/using mass timber buildings of a range of typologies.

3. **A methodology can be refined to assess both whole life carbon and quality of life** for existing mass timber buildings that can be repeated by others in the future.

4. **Mass timber supports generation of a holistic 'whole life value'.** There are synergies to be found from applying this method between quality of life and decarbonisation potential of mass timber.

Further project goals

Beyond our primary research hypotheses (see bottom left), we had a series of further objectives we were hoping this project would address. These were:

1. To make a case for timber in whole life value – for planet and for people

By measuring outcomes of completed mass timber buildings and quantifying their impacts on planet (in terms of carbon emissions) and on people (in terms of wellbeing), we can provide evidence (and a framework for others to provide evidence) that appraises how these buildings perform in practice.

2. To define what exemplary mass timber construction looks like

To develop a method for how to appraise performance of mass timber buildings against industry best practice targets. With this we start to suggest how to deliver exemplary mass timber buildings. Due to industry barriers in delivering mass timber buildings, those who manage to achieve it at all may not sufficiently scrutinise the efficiency and efficacy of mass timber systems, from the perspective of resource use or user satisfaction. We want to define what 'really good' looks like in mass timber, to drive quality in industry for its adoption. With this we hope to demonstrate the replicability of gathering a holistic evidence-base to show quality in mass timber buildings. This could be adopted by awards bodies moving forward.

3. To highlight barriers around mass timber construction and missed opportunities for maximising benefits

Through this study we anticipated that there would be wider issues raised around the implementation of mass timber construction. For instance, where known issues around fire and safety have an impact on carbon or wellbeing. We also wanted to see if there were areas where we were falling short in our ambitions to make the most of mass timber.

4. To support wider adoption of mass timber construction

Part of the challenge in championing mass timber today is lack of consistent data. The majority data exists in terms of commercial viability and embodied carbon (albeit with inconsistent application of methods). We feel that the human experience of mass timber has been to date under-researched. We see an opportunity to present more holistic findings. We hope in so doing, we help others to make a case for timber, supporting its wider adoption.

5. To refine the value system for what good (mass timber) is

By measuring holistic outcomes of completed mass timber buildings, we can provide data (and a framework for others to provide data) that describes performance in relation to best standard targets. This helps us to understand what 'good' looks like in mass timber and as compared to business as usual construction.

6. To support wider adoption of retrospective studies and identify barriers/opportunities for this work

More generally, by undertaking this project and sharing our knowledge with others, we hope to support a shift towards Building Performance Evaluations becoming more standard, together with some of the monitoring approaches we adopted being refined and made easier in the future for others to replicate.

Target audience

Given the wide remit of the research project, there are many potential audiences who may be reading and making use of the findings, so we have sought to make this report as accessible as possible. Our original target stakeholders were identified as:

- Designers – to know what 'good' mass timber looks like and to learn from best practice projects

- Policy makers – to see the case for mass timber and support efforts toward alleviating myths/barriers

- Clients and developers – to understand the widespread benefits from mass timber and how to maximise these

- Institutions and judging bodies – to influence the value system of what good mass timber design is

It is hoped that those involved in education, planning, insurance and forestry will also take interest in the overall appetite and benefits of mass timber construction revealed by the research.

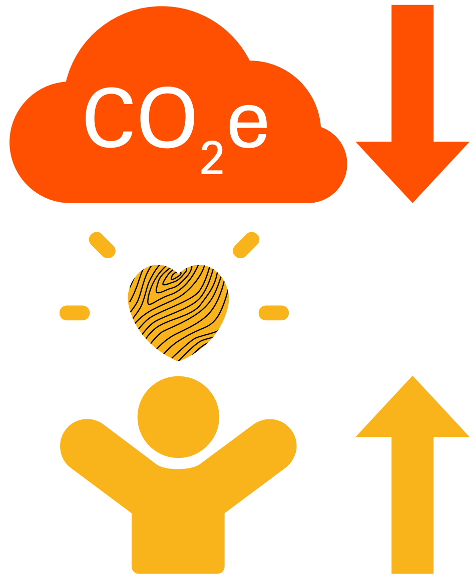


Figure 2. Quality of life will be explored in tandem with carbon

Whole Life Carbon

Whole Life Carbon emissions are the sum total of all asset related GHG emissions and removals, both operational and embodied over the life cycle of an asset including its disposal (Modules: A1-A5 Upfront; B1-B7 In Use; C1-C4 End-of-life). Overall Whole Life Carbon asset performance includes separately reporting the potential benefit from future energy recovery, reuse, and recycling (Module D).[03]

Quality of life

The level to which individuals may feel their lives to be happy, active, sociable, interesting and meaningful. The term often sits alongside 'wellbeing' or 'how we are doing' as individuals, as communities and as a nation, and how sustainable this is for the future. It might be thought of as health as defined by the World Health Organisation: not merely the absence of ill-health but, *'a state of complete physical, mental and social wellbeing'.* [04]

> “ **‘Now is the time to turn rage into action. Every fraction of a degree matters. Every voice can make a difference. And every second counts.’** [05]
>
> António Guterres, Secretary General of the United Nations on IPCC’s AR6 in 2022

Figure 3. A forest fire - one of many climate change-initiated disasters (Photo Mike Lewelling, National Park Service)

Problem context

We think it is important to iterate here the gravity of the global challenges we face. Of nine planetary boundaries assessed by the Stockholm Resilience Centre, we have crossed six.[06] This means that we are beyond the ‘safe operating space’ for life on earth in many aspects.

The Potsdam Institute has in 2024 declared a red alert in their inaugural planetary health check, stating ‘the overall diagnostic is that the patient, Planet Earth, is in critical condition.’[07] Atmospheric carbon dioxide concentration is well beyond the safe level of 350 ppm, or our pre-industrial base of 280ppm, and now is upwards of 420ppm.[08]

The 2023 IPCC Synthesis Report AR6 outlines that growth in **carbon emissions** has persisted since 1990.[09] Already we see significant impacts of climate change, with 2023 the hottest year on record (yet) and worryingly, even climate scientists are ‘confounded’ [10] by the recent speed of heating. We are seeing directly attributable events associated with climate change,[11] and extinction events are already occurring.

Beyond the climate crisis, we know that human quality of life has room for improvement. The percentage of adults in the UK reporting very high levels of life satisfaction has decreased,[12] with an increase in those reporting low satisfaction with their lives since 2019.[13] According to Mind, the mental health charity in the UK, one in four people will experience a mental health problem of some kind each year in England,[14] while one in 13 adults feel lonely often or always.[15]

We therefore face the urgency of addressing the interconnected climate and biodiversity crises, with consequent and interconnected links to issues of social equity and justice.

These issues can be represented in combination through Kate Raworth’s ‘Doughnut Economics’[16] approach of overlaying planetary boundaries with social foundational factors. This highly visual approach can be applied to specific regions, with the mapping above right showing the UK exceeding on carbon emissions and still underperforming on some social foundation aspects which can be seen to relate to how we understand quality of life. Following this interconnected approach, we must seek to simultaneously address decarbonisation (and all planetary boundaries) together with addressing the support of social foundations, including quality of life. Failing to consider holistic, interconnectedness of these issues may mean that interventions create unintended consequences in other parts of the system.

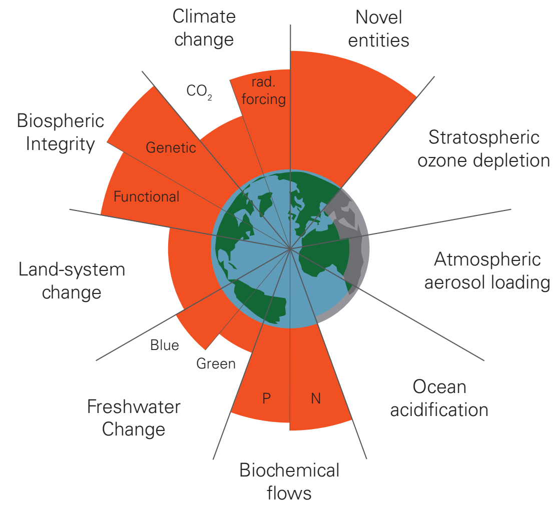


Figure 4. Planetary Boundaries (after Stockholm Resilience Center 2023)

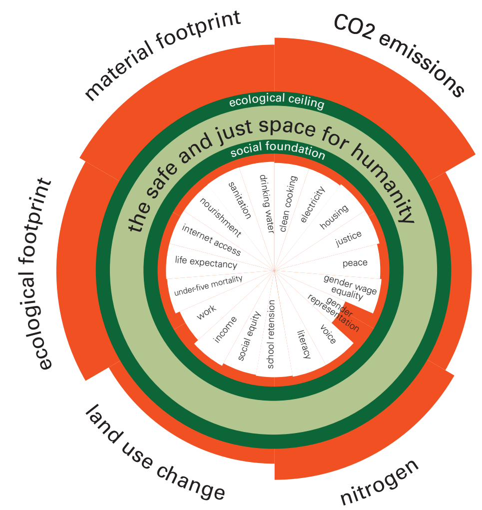


Figure 5. Doughnut Economics tool for the UK [17]

Carbon emissions (CO_2e)

When we talk about carbon emissions, we mean the aggregate process emissions of various gases that contribute to global greenhouse effect. This is recognised as a proxy measurement for climate change or global warming potential (GWP) and is measured in units of carbon dioxide equivalent (CO_2e). In this metric CO_2’s GWP is used as the reference, representing 1 unit of CO_2e. Its concentration is one of the 9 planetary boundaries.

Carbon dioxide is responsible for c. 80% of heating. The rest can be attributed to methane (c.15%), water vapour, ozone, nitrous oxides, fluorinated gases (totalling together the remaining c.5%). By using a standardised unit of CO_2e, we can consider the fuller emissions impacts of these wider greenhouse gases in a single metric – how much carbon dioxide would it take to heat the planet as much as this other gas? How long does it stay in the atmosphere for?

Figure 6. dRMM's Stirling Prize-nominated Trafalgar Place housing scheme saw the completion of two mass timber buildings where the system directly substituted more standard approaches used elsewhere in the scheme. The buildings from the outside are indistinguishable as mass timber. (Photo dRMM)

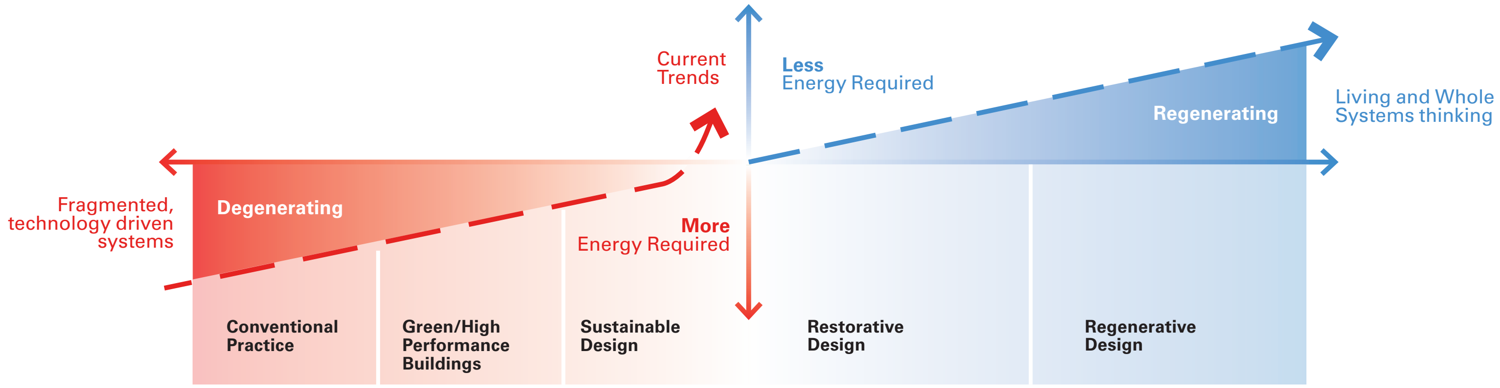


Figure 7. Regenerative design concept diagram (drawn by dRMM from Bill Reed's original diagram)

The built environment's challenges

We know that the built environment is a significant contributor to carbon emissions and has an important role to play in decarbonisation, alongside seeking to support social needs.

In the UK, the UKGBC states the built environment is directly responsible for 25% of carbon emissions and influences around 42% of emissions more widely.[18] The IPCC also highlights the role the built environment can play in decarbonising ahead of some more challenging sectors, such as transport.[19] The IPCC states '*for the carbon embodied in supply chains to become net-zero, all key infrastructure and provisioning systems will need to be decarbonised, including electricity, mobility, food, water supply, and construction.*'[20] We know that the status quo for how we design, construct, maintain, operate and deconstruct the built environment needs to change in response.

At the same time, we know that the built environment affects human health and wellbeing, or what we prefer to term as 'quality of life'. We are thought to spend 80-90% of our lives indoors.[21] The air that we breathe and the surfaces we look at contribute to our mental and physical wellbeing. But we simply do not know enough about how much the built environment's make up affects this and which factors drive improved outcomes for human quality of life together with decarbonisation goals being met.

There is a groundswell of enthusiasm and drive to change the paradigm for how the built environment is designed, built, maintained, operated and deconstructed in the UK in recognition of these shortfalls. Initiatives such as Architects Declare[22], Architects Climate Action Network (ACAN)[23] and the Low Energy Transformation Initiative (LETI) have all contributed to furthering this shift in the UK in recent years, alongside longer-running organisations including UKGBC, ASBP and TDUK. These industry initiatives have widespread appeal, with 1370 practices supporting Architects Declare at the time of writing.[24] AD and ACAN have also spawned international sister organisations, both across countries/continents and a breadth of professional roles in the built environment.

From these initiatives and increased interest, there is starting to be good understanding for what best practice in the built environment is, particularly for decarbonisation, for instance with work by LETI, UKGBC and the Net Zero Carbon Building Standard (NZCBS) developing a consensus around low carbon design best practice and with measurement best practices well developed (see Methodology for more). There is also a grassroots initiative seeking to regulate embodied and whole life carbon emissions, with a proposed 'Part Z'.[25] In London and some other areas Whole Life Carbon is analysed at planning stage. We expect it is very likely that in the next five to ten years this will become nationally regulated. Other planetary boundaries are less well explored and regulated.

Quality of life and the Doughnut Economics 'social foundation' aspects are less well developed than the carbon-related planetary boundary aspect, although increasingly addressed as a facet of regenerative design best practice. This has started to be addressed in work including Architects Declare's Regenerative Design Guide (2024)[26] which uses the Doughnut Economics approach translated to the built environment, considering regenerative design to include three principles; 'creating a just space for people', 'co-evolving with nature' and 'becoming a good ancestor'. The latter principle is further defined as a need to ensure 'social connection, economic opportunity and wellbeing for all'.[27]

Architects Declare recommend, among other aspects, the following regenerative design principles on projects:

- *'Materials are selected and sourced more locally, aiming to use biobased and waste materials, with buildings seen as carbon sinks'*
- *'The built environment remediates the harm that has resulted from years of conventional development, with materials and processes providing positive impact to communities'* [28]

This report explored all these aspects.

Regenerative design

'Regenerative design is an approach in which human systems are designed to co-exist and co-evolve with natural systems over time. [...] *it proposes to deliver a net positive impact for the environment by replenishing resources and enhancing resilience.Regenerative design mimics natural ecosystem processes, which keep cycling and transforming materials and grow healthier and more diverse ecosystems. It uses a systems approach to create resilient and equitable systems that integrate the needs of society with those of nature. [...]By doing so, it delivers positive environmental and social outcomes, ensuring both human and planetary health.'* [29]

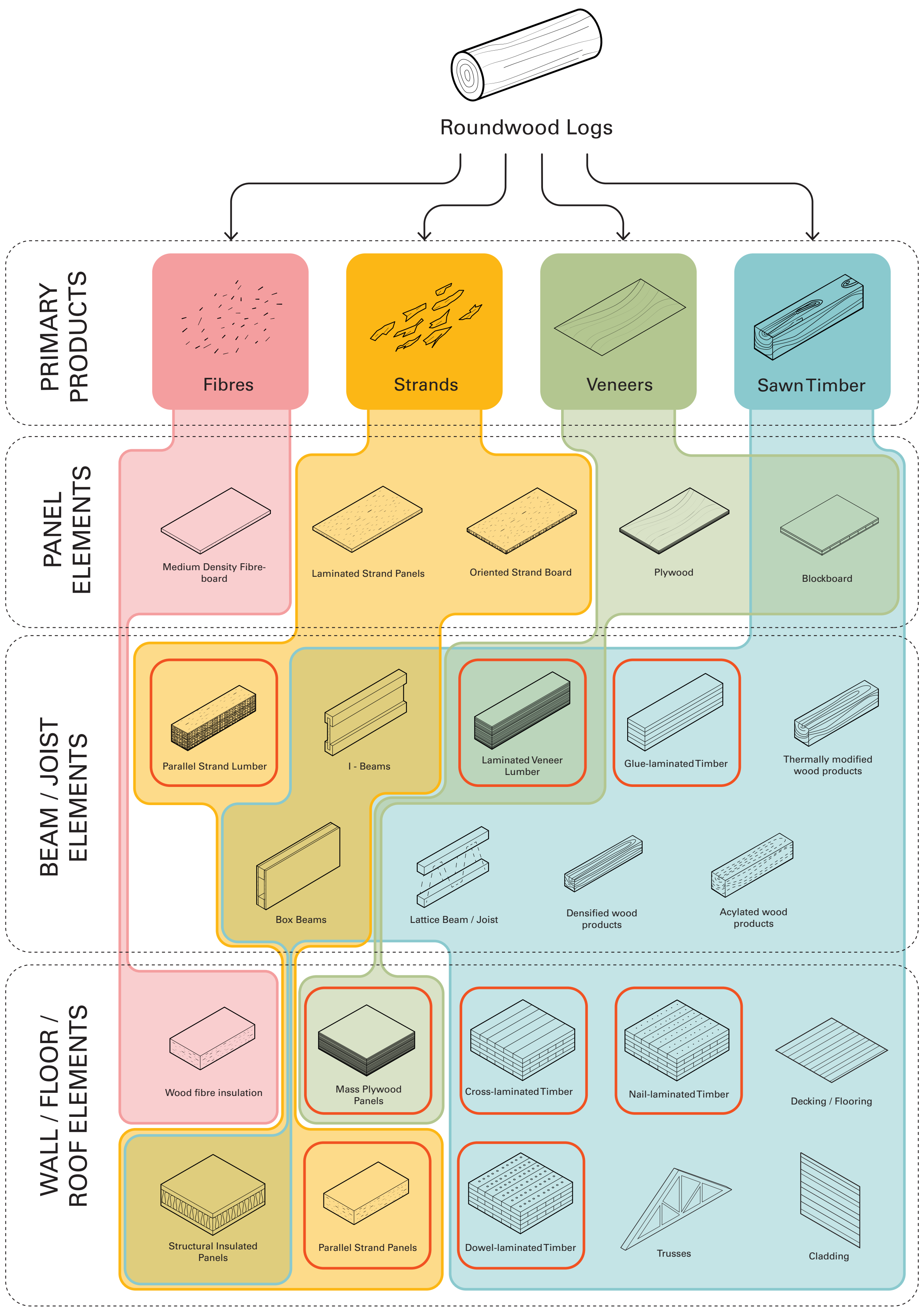


Figure 8. Mass timber products inventory

Key

Mass timber products

Mass timber

We posit that mass timber construction has the potential to offer a decarbonisation solution and improve human quality of life simultaneously, but to what extent? We will explore the evidence and experience that demonstrates this potential, while the latter parts of this report will then explore how this can be measured and impacts optimised through real project case studies.

Timber is a naturally renewable **biobased** material, with the potential to support a shift from our current degenerative culture to a true regenerative design. To state the very obvious - all timber products originate from roundwood logs felled from forests or woodlands. The four main primary products of fibres, strands, veneers and sawn timber can then be processed into a range of panel elemens, beam/joist elements and wall/floor/roof elements (as illustrated left). While a range of **mass timber** products exist, the majority of construction is at present limited to CLT and GLT in the UK market. We are seeing increasing prevalence of LVL and other hybrid mass timber systems come to the fore in our own work as architects and academics, with a focus on greater diversity of timber species, forest products and on structural efficiency with minimum resource quantities - all areas under exploration at present.

This report specifically focuses on the role of mass timber construction as opposed to structural timber frame or other wood-based/biobased construction methods. The reason for this distinction is due to the belief of the research team for the potential for mass timber to displace construction methods such as steel and concrete in larger, more complex building types today. We know how to do this and there is real potential to do so at scale in the short term. The market case for use of structural timber frame in lower rise buildings is more well-established and understood, together with an understanding of the role in decarbonising construction of these building typologies.[30] Guidance and exploration into low-rise and structural timber best practice would be perhaps useful, but is outside the scope of this study.

In this report, we will generally focus on mid- to high-rise buildings. These are building typologies usually constructed in other 'high carbon materials' such as steel and concrete, or where structural timber would usually not be viable due to performance or procurement constraints.

Timber

Timber refers to the wood of trees that can or will be used for building materials. Timber and wood are often used interchangeably.

'Wood is the principal strengthening and nutrient-conducting tissue of trees and other plants. It is strong in relation to its weight, is insulating to heat and electricity, and has desirable acoustic properties. Furthermore, it imparts a feeling of "warmth" not possessed by competing materials such as metals or stone, and it is relatively easily worked. As a material, wood has been in service since humans appeared on Earth.' [31]

Mass timber

"'Mass timber' refers to engineered wood products that are laminated from smaller boards or lamella into larger structural components such as glue-laminated (glulam) beams or cross-laminated timber (CLT) panels. Methods of mass-timber production that include finger-jointing, longitudinal and transverse lamination with both liquid adhesive and mechanical fasteners, have allowed for the reformulation of large structural timbers. The parallel-to-grain strength of mass (engineered) timber is similar to that of reinforced concrete (Ramage et al. 2017). As much as half the weight of a given volume of wood is carbon, sequestered during forest growth as a by-product of photosynthesis (Martin et al. 2018)."

(IPCC AR6)

This is an umbrella term used to incorporate a range of engineered wood products including:

- Glulam/GLT - glue-laminated timber
- CLT – cross-laminated timber
- DLT – dowel laminated timber
- NLT – nail laminated timber
- LVL – laminated veneer lumber
- LSL - laminated strand lumber
- PSL - parallel strand lumber
- CLST – cross laminated secondary timber (using reused timber elements, an emergent area)

What these engineered wood products all have in common is that they are made up of smaller elements that are somehow connected to make larger, stronger, more massive elements. Mass timber elements are load-bearing.

Figure 9. dRMM's Kingsdale School. An early example of CLT construction in the UK (Photo dRMM)

Mass timber in the UK

It is not currently known how much mass timber construction contributes to the overall make up of building stock in the UK market. For housing, we do at least know that the structural timber frame industry is responsible for 22% of the UK housing market, with a market value of £690m according to the Structural Timber Association.[32]

It would be useful for similar studies to be undertaken to appraise the role of mass timber in construction and to understand market trends, particularly in relation to recent regulatory changes in the UK market. What we do know is that mass timber is only quite recently being deployed at scale in the UK. Glulam was developed in the late 19th century, but with GLT limited generally to arches, columns and beams, and with limitations then in glue and cutting technologies, was limited in its ability to displace significantly other construction systems. It wasn't until CLT's introduction in the 1990s that mass timber started to be widely adopted. dRMM's Kingsdale Academy (left) is an early example of CLT construction, designed and built between 1998-2007. Waugh Thistleton's '100 Projects UK CLT'[33] book charts 100 'noteworthy' CLT projects between 2005-2018, with mapping showing a prevalence towards London and the south-east. This book includes high level carbon appraisals of each building, although with the book written in 2018, the methodology is not in line with current guidance. TDUK's website features 71 mass timber case studies.[34] It is not known how many mass timber buildings now exist in the UK in total, with notably large-scale roll-outs by commercial, retail and hotel chains without input from architecture practices.

In recent years, it has been challenging to deliver mass timber, or any combustible biobased construction, in the UK market following the 2017 Grenfell fire tragedy and subsequent building regulation and insurance market reaction. Combustible materials are now banned in external walls of residential/institutional buildings over 18m above ground level.[35] This has anecdotally contributed to the slowdown of procurement of mass timber in these and other typology markets and industry efforts have been seeking to address these challenges.

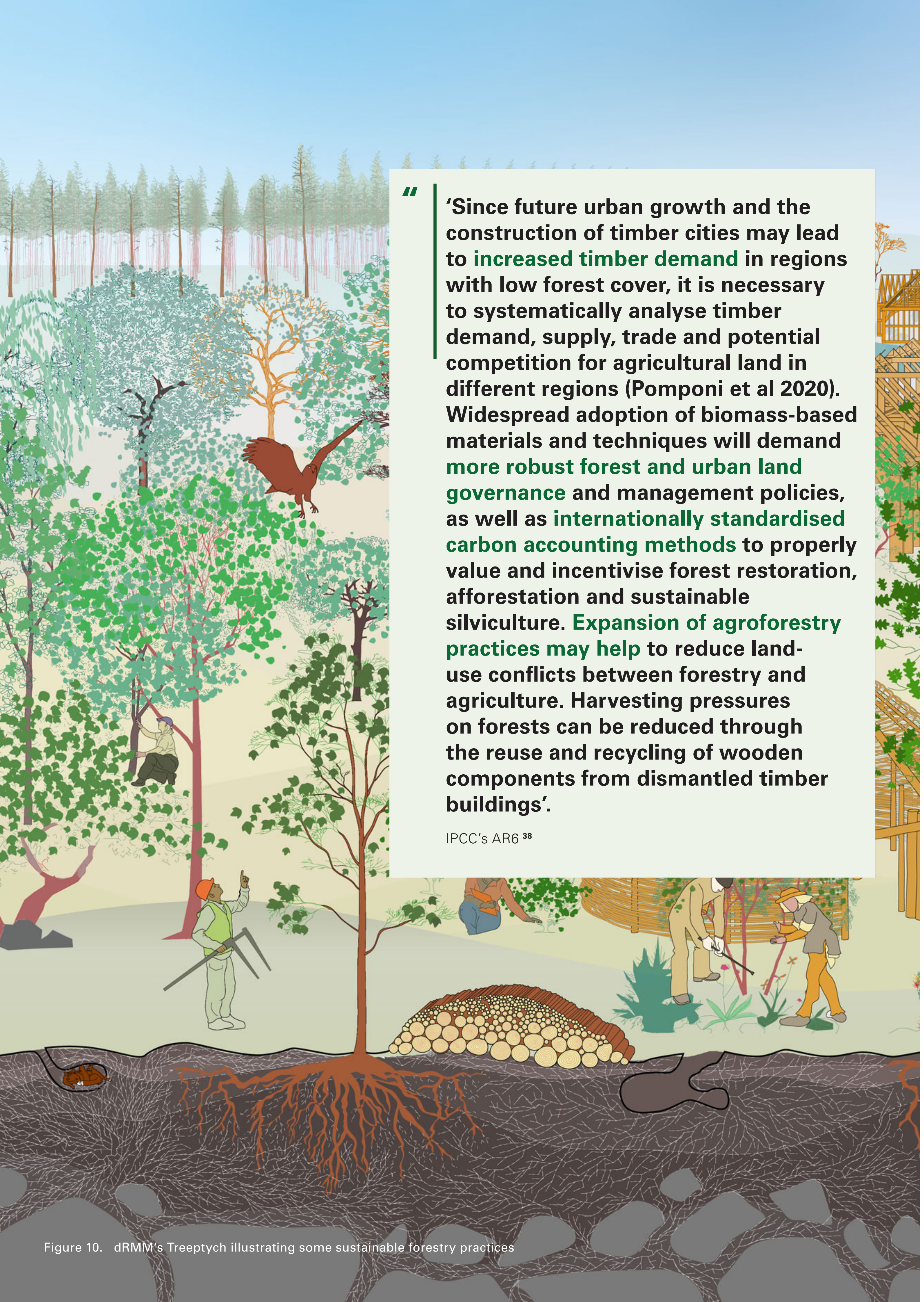
The CCC's report ***Wood in Construction in the UK: An Analysis of Carbon Abatement Potential*** identified that 'use of timber can reduce the embodied emissions in a single building by 20% to 60%.' This has led to the CCC recommending government 'develop new policies to increase the use of wood in construction' and a Timber in Construction roadmap [36] has been subsequently established.

To be explored further

It has not been possible in this research project to understand the full extent and proportion of mass timber construction as a part of the UK construction market as compared to other construction systems. We would hypothesise that mass timber represents a fairly small proportion, due to the relative recency in mass timber emerging as a construction method and it not yet being widely adopted.

We hypothesise a relatively higher proportion of what is built in mass timber in some sectors (hospitality, residential pre-dating 2019, education), and less represented in others (infrastructure, healthcare, commercial). We would suggest undertaking comprehensive research into investigating the stock of mass timber in the UK and key typologies covered would be valuable, to ensure that industry efforts are working to affect areas with most substantial potential for change.

What we do know is that the majority of timber products are currently imported to the UK. And even more so for mass timber, with very small scale production here in the UK. According to data from TDUK, mass timber products represent under 0.75% of UK total timber imports.[37]



> **‘Since future urban growth and the construction of timber cities may lead to increased timber demand in regions with low forest cover, it is necessary to systematically analyse timber demand, supply, trade and potential competition for agricultural land in different regions (Pomponi et al 2020). Widespread adoption of biomass-based materials and techniques will demand more robust forest and urban land governance and management policies, as well as internationally standardised carbon accounting methods to properly value and incentivise forest restoration, afforestation and sustainable silviculture. Expansion of agroforestry practices may help to reduce land-use conflicts between forestry and agriculture. Harvesting pressures on forests can be reduced through the reuse and recycling of wooden components from dismantled timber buildings’.**
>
> IPCC’s AR6 [38]

Figure 10. dRMM’s Treeptych illustrating some sustainable forestry practices

Sustainable forestry

Sustainable, responsible sourcing is a fundamental prerequisite to mass timber’s use in seeking to pursue decarbonisation and quality of life enhancements. The underlying need for forests to be managed sustainably cannot be understated.

As outlined in the IPCC AR6 Report, *‘transitioning to biomass-based building materials, implemented through the adoption of engineered structural timber products and assemblies, will succeed as a mitigation strategy only if working forests are managed and harvested sustainably’.*[39] It is an assumption henceforth in this report that whenever we are writing about mass timber systems that this is always to be sustainably and responsibly sourced. The IPCC have also highlighted [40] (quote left) the reciprocal relationship between carbon incentives for biobased materials to support improved sustainable forestry practices. As forests and woodlands are being looked to as potential solutions for providing carbon credits, there is potential for rising afforestation. Knowing that harvesting timber contributes to increased levels of carbon sequestration in the woodland system is important. If that timber, thus carbon, can then be held in long-term storage then there is even further benefit to be had, as compared to alternatives like producing biomass pellets where the carbon is soon released, or for short-lived products.

More sustainable forestry practices also support enhanced sequestration and storage, even as compared to unmanaged woodlands.[41] This is something that people can be confused by, believing that the commercial timber felling process is the same as ‘deforestation’. The key distinction being that sustainably managed woodland does not allow depletion of overall biomass over the whole system over time. It is admittedly perhaps counterintuitive to those without an understanding of forests, or who believe humans to be a net force for bad in all natural systems (who should read ‘Braiding Sweetgrass’ and Robin Wall Kimmerer’s description of ‘honourable harvest’ [42]), to appreciate that humans can be a positive in woodland ecosystems. Life and death coexist in fine balance in a sustainably managed forest. Dead materials support new life.

It is worth noting that other extractive material resources are fundamentally un-sustainable in their depletion of finite natural resources, particularly at current extraction rates. We cannot sustain our current level of extractive resource use, even if supply and manufacture methods do decarbonise significantly. That timber can be sustainably managed and is naturally renewable is an important distinction as compared to non-biobased materials.

Sustainably sourced timber

‘To be sustainable, timber must be grown and harvested in responsibly managed forests, which are continually replenished and regenerated. Balancing the needs of wildlife, environment and local community, sustainably managed forests provide numerous benefits from carbon capture and flood risk mitigation to the preservation of biodiversity and provision of local livelihoods. (...)

Certification standards, such as FSC, or PEFC, and Grown in Britain certified wood, confirms that the timber is sourced from responsibly managed forests via Chain of Custody throughout the full timber supply chain.’ [43]

For fuller information refer to TDUK’s guide ‘Sourcing Timber Sustainably’ (2023).[44]

Key takeaways

It is essential that all timber is sustainably and responsibly sourced. Sustainably managed woodlands can sequester more carbon than unmanaged woodlands. That timber can be sustainably managed and is naturally renewable is an important distinction as compared to non-biobased, finite resource materials.

To be explored further

Exploring the potential for best practice for sustainable forestry and timber specification is an area that itself warrants further research. More work is needed to understand the role of architects and those in planning/development positions in supporting more sustainable, biodiverse forestry practices.

dRMM is currently working on a separate research paper in collaboration with the BE-ST and Ecosystems Technologies looking at the role of Homegrown Timber and making harvested wood products from British wood supply in an effort to diversify supply chains and support responsible sourcing in the UK.[45] You can also read about dRMM’s perspective on sustainable forestry and timber management in our ‘Treelogy’ from 2021 [46]; Part I - Learning from Woodlands [47]; Part II - The Tree and Timber [48]; and Part III - The Urban Forest.

Figure 11. Illustration of decarbonisation impacts of mass timber.

Decarbonisation

Key takeaways

The decarbonisation role of mass timber is not solely confined to its associated biogenic carbon, but across a range of factors.

How does mass timber support decarbonisation?

We understand that timber and biobased materials support decarbonisation, but how about mass timber specifically? There are a few ways that mass timber supports decarbonisation (most of these also apply to the use of biobased/natural materials more generally) that are well established by both evidence and experience:

1. Sequestration

Biobased materials including timber sequester carbon through their growing phases, drawing carbon from the atmosphere via processes including photosynthesis and the making of biogenic material. (See Methodology for more on definitions for Sequestration and Storage).

2. Storage

When the sequestered biogenic carbon is continued to be locked away over a longer timespan, storage of carbon occurs. To maximise storage, we need to prevent the reintroduction of carbon back into the atmosphere for as long as possible. We know that there are timber buildings standing that have lasted for hundreds, even thousands of years in timber. For example Greensted Church in Ongar, Essex, UK (pictured opposite top right) is thought to be the world's oldest timber church and the oldest timber building in Europe, with timber elements dating from the 9th-11th Century. Mass timber in construction is a relatively recent approach, though there are buildings that have been standing for upwards of 100 years made from mass timber, including at Malmö station, with glulam arches supporting the roof since 1924.[49]

If designed for circular economy and reuse, then timber products have the potential to store carbon over long timespans even when a particular building is no longer needed. Even if those carbon stores are later released back into the atmosphere, arguably there is a benefit to delaying emissions – as 'through delaying emissions we retain the opportunity to avert them'.[50] We need to be considerate of fire, water/moisture and pest risks to extend this lifespan as long as is possible - more on risks overleaf.

3. Substitution

Substituting carbon intensive technical materials with regenerative resources and materials from the biosphere, which absorb and store natural carbon – has become a key approach to decarbonising our built environment.[51] Where biobased materials including timber are used in place of other higher carbon materials, there is potential to have a substitution impact in upfront carbon. In the case of mass timber, this is quite a high potential as mass timber can be used as an alternative to concrete and steel.

Also at end-of-life there is potential for substitution to occur again, either by timber assets being repurposed in a circular economy and substituting the use of virgin/high carbon resources, or where this is not possible by substituting biomass in heat generation, in place of virgin timber. We think it will become increasingly unlikely that there will be a net emission at end-of-life, however for now, we should defer to best practice data (see Methodology section for wider discussion on this).

4. Knock-on efficiencies

We have seen on our own projects at dRMM the potential for mass timber buildings to limit use of additional layers of materials and products, for instance where the structural finish is expressed as a final finish rather than hidden away. Mass timber can be 20-30% lighter than other systems, resulting in less massive foundations required, thus reducing carbon impacts and resource use. There are also efficiencies to be found in the construction process, as mass timber lends well to Design for Manufacture, Assembly and Disassembly (DfMA+D) approaches and the efficiencies arising from off-site pre-fabrication.

5. Renewable and circularity potential

Biobased materials, 'when sustainably and responsibly sourced', have a potential through their inherent renewability to support a circular economy. Mass timber in particular contributes to the potential of a circular economy in construction as Adrian Campbell has outlined in his paper 'Mass timber in the circular economy: Paradigm in practice?'.[52] There is end-of-life potential for mass timber systems to be repurposed in future structures and systems, and design of structures can make this more likely when considered now. And in terms of upfront embodied carbon, there is research being undertaken in the field of CLST to form engineered timber of secondary timber products as opposed to new timber.

6. Forestry and carbon sinks

In specifying and working with sustainably sourced timber, we support the economies related to sustainable forestry management and processing, contributing to the realisation that forests are worthwhile investments and to support efforts to curb deforestation. Sustainable actively managed forests can sequester more carbon than those that are unmanaged. Supporting silviculture, biodiversity and positive forestry practices is essential for ensuring these remain carbon sinks and not net-carbon emitters.

What are the barriers or risks in use of mass timber towards decarbonisation?

We also know there are limitations or challenges in maximising the decarbonisation potential of mass timber in reality when building under real-world scenarios. These are areas where the use of mass timber is often critiqued, and without more robust research, we feel will continue to be challenging obstacles to overcome. These risk areas, or areas of potential risk for timber as a tool for decarbonisation, include:

1. Massive by name, massive by nature. CLT has been jokingly referred to as 'Contains Lots of Timber' and this is a key area of critique. Is there a tipping point beyond which it becomes more high carbon and less efficient to use mass timber over leaner structural systems? We wrote about this in dRMM's 2021 'Treelogy':

'As there is a limit to sustainable extraction rates from forests, and a likely increased future dependence on our forests to provide us with building materials, we cannot be putting more timber in buildings to seek exaggerated sequestration goals on a project-by-project basis. We instead need to be making more buildings out of timber, with each one using timber as efficiently as possible.'[53]

How we measure and give weight to the role of storage of carbon in mass timber construction is a really critical part of ensuring we do not inadvertently incentivise inefficient use of this natural resource. This is something this project addresses through the methodology implementation and recommendations. An area of current research beyond this report that the research team members dRMM and ENU are involved in is to explore new, more efficient mass timber products that use less material to do more.

2. Encapsulation for fire and acoustics The layers of plasterboard and other products used to encapsulate mass timber structures for fire and acoustic purposes add a need for additional material and therefore a likely carbon burden, which may not be factored in a like for like comparison of structural systems in early stages of material selection. This also interrelates with the discussion on the role of natural materials' biophilic potential being affected by encapsulation. This is not explored in depth in this research project, although we will touch on it in discussion of our case studies.

3. Transport emissions At present the UK imports 62% of all timber.[54] The statistic is likely to be much higher for mass timber given the very small number of manufacturers in the UK, with import of mass timber most likely in excess of 95% according to TDUK. There is potential for the transport related carbon emissions to be higher therefore for this as compared to other material systems that are produced more locally. According to IStructE's paper 'Transporting carbon: calculating A4 emissions for mass timber', as a proportion of A1-A5 emissions, transport for mass timber (A4) generally sit at around 35-37% compared to 4% for concrete and 2% for steel. But when we compare mass timber to alternatives it is lower upfront carbon by weight, even with higher proportional transport emissions. This means there is significant potential for timber products to reduce their carbon emissions through transport systems decarbonisation and refinement of haulage logistics. IStructE have found that improved haulage logistics can reduce carbon emissions associated with A4 transport by 26% compared to default assumptions. Reductions in transport emissions will have a greater impact on the embodied carbon impact of timber products than on alternative systems as a result of the disproportionately large role transport plays.

4. Moisture and pests The risk of moisture is of concern during construction stages, where rain and humidity is inevitably absorbed in timber structures to varying degrees depending on site management practices. Some level of moisture absorption is tolerable, to a point, but unsafe thresholds should not be passed and consideration should be made to allow sufficient drying time and protection. This risk should be managed carefully and monitored. During a building's occupation there is further risk of leaks and flaws in construction/design to allow water and moisture to affect the structure over long timeframes, resulting potentially in latent defects.

Monitoring devices are available for monitoring both the construction and operational lifetime of mass timber buildings, such as that by Danish company Tector. This approach has been implemented in UK project 'Llama Croft' already, yielding positive outcomes for detection, analysis and learning about how timber performs over time.

Pests are of increasing concern with climate change bringing new species to the UK. Designers should be considerate to these risks in how they detail mass timber buildings to limit forseeable risk as far as possible, as of course water-damaged or pest-affected elements are more likely to be discarded at end-of-life and may need more frequent replacement during their lifetimes than anticipated in carbon analysis now.

5. Manufacture emissions Other major emission sources for timber products would be on forestry and manufacturing methods that involve fossil fuel-based systems. As with all material supply chains, decarbonisation of the electricity grid also offers potential to further decarbonise. Kiln-drying and heat processing will be higher energy aspects of timber supply chains that might be particularly common in the case of mass timber where curving forms and complexity is pursued.

6. Fixings, joints and treatments These aspects of mass timber systems are potentially significant carbon emitters upfront, while also affecting the end-of-life prospects for reuse and deconstruction. Often fixings are metal-based, while fire retardant coatings and glues that are non-biobased affect end-of-life biodegradability and reusability. Screw based fixings can be better from a circularity standpoint, while there are examples of mass timber systems (e.g. dowel laminated timber) that avoid adhesives.

7. Multi party-processing and DfMA The nature of mass timber is that it quite often involves a lot of prefabrication off-site. Generally this is seen as a positive, however there are potentially areas of increased carbon through the transport of large and heavy structural elements, as well as the risk of lack of data as we move from an off the shelf panel of a CLT element towards bespoke elements that are CNC routed with openings etc. by another party.

8. Deforestation and degradation While we have noted the positive potential of specifying timber as a carbon advantage, we also know that there is a risk that poor management of forests can lead to net adverse outcomes (the worrying outcome of forests becoming net emitters rather than sinks). This should not be a risk in the case of sustainable forestry, however we have included here as a consideration to hold in mind as part of the reason for the emphasis we have made on sustainable forerstry as a paramount basis for all timber construction.

9. End-of-life spectrum of outcomes A key source of uncertainty in predicting now the likely impacts of timber structures far into the future is how the timber assets are handled at end-of-life. Diverse outcomes range from combustion (incineration of waste) where the carbon would be fully released, to continued use in perpetuity (or enough to be classed as 'permanent' carbon storage), or compost where the material breaks down as part of a natural cycle (but still releases carbon and methane to the atmosphere, but materials are used meaningfully in an ecological process).

10. Local supply chains and fair share This report is written from a UK perspective. Mass timber's suitability should be considered in relation to local supply chains and material availabilities. In Europe, there is a supply of sustainably sourced mass timber, however in other markets this is not the case and engineered timber supply chains are not yet established. We should be mindful too of taking a fair share of available resources, including naturally renewable biobased materials. There is a finite amount of land available for forestry practices and so we should be careful to design efficiently and consciously with timber products.

How does this research project take these into account?

This project has sought to anticipate and be mindful of these risks in how we have appraised the five case study buildings, as far as reasonable, within the limits of the scope of study. We have followed best practice guidance for carbon accounting, of biogenic carbon and end-of-life assumptions in particular of note here, which are covered in some depth in the Methodology section.

We hope that through evaluating actual buildings we can throw some light on how these concerns are addressed and how they influence the performance for carbon and quality of life more widely. In addition to this, whether mass timber buildings are fulfilling their potential for decarbonisation as much as we would like to think, or if there are opportunities for betterment, or barriers to their fullest potential.

This list of risks and barriers is by no means exhaustive in detail or range, so those who are exploring mass timber as potential decarbonisation solutions should be ready to research more widely the specifics of the carbon impacts relating to their design approaches to ensure their designs do not produce other unexpected emissions in their lifecycles. For more information on insurance related best practice in particular, see the ASBP's 'Mass Timber Insurance Playbook' and the Timber Accelerator Hub's 'Mass Timber: Challenges & Potential Solutions'.

Key takeaways

While mass timber offers decarbonisation potential, there are limiting factors to the extent and duration of this impact. These limitations/challenges should be considered upfront in designing mass timber buildings to maximise decarbonisation over a whole life.

Biogenic carbon can be stored over long timeframes where buildings are designed to protect the mass timber structure from risks (fire, moisture, pests etc.) and when designed for circularity at end-of-life.

CONNECTED COMMUNITIES

A SENSE OF CONTROL

HEALTH EQUITY

GETTING AROUND WITH EASE

CONNECTION TO NATURE

A SENSE OF WONDER

Figure 12. Six themes of the Quality of Life Framework (QoLF)

Quality of life

We have explored how mass timber buildings support decarbonisation. Now, we turn to how mass timber buildings might enhance quality of life and assess the current state of literature and understanding on this aspect.

We know that people's experience of the built environment strongly impacts quality of life, both of humans and other species. This report focuses on the impacts on human quality of life rather than 'life' in a broader sense incorporating wider ecosystems and non-human living species. A more inter-species perspective would be positive to explore in future research appraising impacts of biobased materials.

Quality of life and wellbeing can be supported, or infringed upon, by the places in which people's lives play out. Human lives are more than ever before playing out in urban places and indoors. We are increasingly urban as a species, with more than half of the world's population now living in urban areas. The UK is one of the most urbanised countries, with 82.9% of England's population in urban areas.[55] It is estimated that in the UK we spend 80-90% of our time indoors in places 'such as in the home, schools, workplaces, public places and when using public transport (enclosed buildings such as some train stations).[56]

According to research published in the University of Oxford Journal for Public Health; *'The built environment exerts one of the strongest directly measurable effects on physical and mental health, yet the evidence base underpinning the design of healthy urban planning is not fully developed.'*[57] And yet, in the 'UK, 4.6 million homes (19% of the total) failed to meet the decent home standard in 2015', and while there has been a fair amount of research into domestic settings in influencing wellbeing 'there are significant gaps in the evidence in relation to non-residential buildings for design and health'.[58]

We believe that there is limited research into the role mass timber specifically plays into quality of life, as this is a relatively recent term, as distinct from and building upon 'wellbeing' as a concept. While the link between buildings and quality of life is known to be incredibly strong, measuring and unpicking how buildings affect quality of life individually can be more challenging given the multifaceted nature of what contributes to quality of life.

Quality of life

The Quality of Life Foundation has identified six key themes driving quality of life in relation to the built environment:

1. A sense of control
2. Health equity
3. Connection to nature
4. A sense of wonder
5. Getting around
6. Connected communities

The Quality of Life Foundation has been undertaking evaluations on a range of projects to see how buildings are affecting individuals' quality of life. Generally, post-occupancy evaluations (POE) and Building Performance Evaluations (BPE) have tended to focus on measurable aspects (including air quality) and user satisfaction (including on thermal comfort, light, acoustics etc.), but may not extend to give a full understanding of how buildings affect quality of life in a qualitative sense on wider themes such as 'control', 'wonder' and 'connection to nature'.

The purpose of BPEs and POEs tends to be on ensuring design quality is met and identifying issues with construction quality or system implementation on buildings, which of course affect quality of life, but without this concept being central to the research question we believe more is not being measured and understood. We have sought to make headway on this in this research project.

Quality of life and mass timber

One of the contributing factors to how buildings affect quality of life is through material selection. This relates to health equity in terms of internal air quality being affected by material surfaces, as well as a more esoteric role in connection to nature where natural materials are adopted, evoking a sense of wonder.

There is some research in this area already. Use of natural materials including exposed timber has been found to support improved wellbeing. For instance, the frequently cited 'Schule ohne Stress' (Schools without Stress) study (2010) identified that stress levels, sleeping patterns and heart rates were improved in students studying in timber classrooms compared to those with more generic school materials (e.g. linoleum, plasterboard).[59] '*14 Patterns of Biophilic Design: Improving Health & Wellbeing in the Built Environment'* found that timber buildings can result in 'improved mental engagement, alertness, concentration, physiological and psychological responsiveness'.[60] Other research has 'observed that people tend to have a positive attitude towards wood, perceiving it as a natural, warm, and healthy material'.[61]

The use of exposed timber relates to the concept of **biophilia**. Use of natural materials, e.g. timber with grain patterns, is one aspect of **biophilic design** that has been proposed to support wellbeing via an 'indirect connection with nature'[62] in Kellert's definition of the term in his landmark book, 'The Practice of Biophilic Design'. The visual connection through materials is particularly important, as 'visual sense is by far the dominant way people perceive and respond to the natural world.'[63] Biophilic design is still an emerging area of research, and its impacts on quality of life deserve further attention.

Mass timber differs from timber products that are less engineered, particularly in the use of adhesive types. These have potential to affect quality of life through air quality and release of VOCs. There is also the question of whether the lamination method in any way changes the potential benefits arising from exposed natural materials which are better understood by previously mentioned research. Limited studies have been undertaken to explore how mass timber contributes to health, through investigating internal air quality specifically including one US paper '*Monitored Indoor Environmental Quality of a Mass Timber Office Building: A Case Study*'.[64] The findings from this one study were of interest for further exploration, with formaldehyde levels detected (below recommended thresholds and source unknown), and with vibrations being below 'recognised human comfort thresholds.' There is some discussion in '*A review of the performance and benefits of mass timber as an alternative to concrete and steel*'[65] for improving the sustainability of structures on the potential for non-adhesive based engineered timber systems to offer better internal air quality, e.g. dowel laminated timber.

There is still room for further research into the ways that natural materials affect quality of life, in a wider range of typologies and user groups. Certainly lacking is the wider perspective around other aspects forming 'quality of life' - security, happiness etc. This project seeks to make progress in this area of study.

Biophilia

"The inherent human inclination to affiliate with natural systems and processes, most particularly life and life-like (e.g. ecosystems) features of the non-human environment"[66]

Biophilic design

Addresses '*deficiencies of contemporary building and landscape practice by establishing a new framework for the satisfying experience of nature in the built environment... Biophilic design seeks to create good habitat for people as a biological organism in the modern built environment that advances people's health, fitness and wellbeing'.* [68]

To be explored further

- Mass timber impact upon non-human life, whether through the forestry and harvesting stage, manufacture, in-use and end-of-life impacts. Further research is required into the ecological impacts and best practice for design and construction of mass timber buildings and more generally.
- Quality of life in this research project focuses on the impacts associated with in-use impacts for those occupying buildings. There is potential to appraise the impacts on construction and manufacturing workers using mass timber. The construction worker community in the UK has high rates of suicide and mental health issues.[67]

Bringing it all together

The case for further research

We have looked separately at how decarbonisation and quality of life in relation to mass timber are evidenced and have identified gaps in both aspects, with greater gaps in the quality of life component.

Furthermore, there is not much research we are aware of that links these two important factors and considers mass timber more 'in the round' with this full range of perspectives – carbon and quality of life. We believe as such that the construction industry lacks both quantitative and qualitative comparable data to support a shift towards greater adoption of mass timber. The data that is being developed is piecemeal and inconsistent, particularly for non-carbon aspects. We are finding not enough studies are done to consider buildings in the round and how they are performing in-use and as constructed, as opposed to as estimated at the design stages. It is important to note that this is reflective of the UK industry at large failing to undertake post-occupancy evaluations and assess buildings retrospectively and not necessarily a failing of those delivering mass timber buildings alone.

A lot of recent industry attention on addressing the challenges of implementing the use of mass timber (in relation to fire predominantly – see the 'New Model Building' (by Waugh Thistleton Architects, UCL, Buro Happold, Gardiner & Theobald, with Built by Nature funding),[69] which is 'an innovative approach to building multi-storey mass timber housing, pre-assessed by a UK warranty provider'. See also the 'Mass Timber Insurance Playbook' (by ASBP MTRC, Glockling et al, with Built by Nature funding).[70] Both of these studies have been hugely important and useful. However, we saw a need to build momentum and better communicate the perceived 'positives' of mass timber (carbon and wellbeing/quality of life) and build more robust methodology for appraising these with consistency and to ensure that industry is not 'greenwashing' through the limited data it does share. We have seen numerous examples of claims to carbon performance (carbon neutrality, carbon positive, carbon negative…) that do not follow current standard methodologies for carbon assessment, which we feel is confusing to a wider audience and means we are not all on a level playing field when it comes to reporting carbon impacts of mass timber buildings. Communication of impacts in a clear manner is essential for supporting well-informed, evidence-motivated decision making.

We are also seeing an emphasis on embodied carbon in industry in absence of more holistic carbon factors – we are often only decision-making on evidence for carbon and cost. The lack of data for other factors means that decisions are being made on what data is readily available.

In the UK, the construction industry has been addressing challenges with building in mass timber following the Grenfell Tower tragedy and the changes in construction regulations for residential buildings, together with risk appetite more generally for certifying structures in other sectors in relation to both fire and water damage. Some headway has been achieved on changing the situation for the better (e.g. Mass Timber Playbook), but we feel exploring in more detail the role of mass timber buildings in decarbonisation and contributing to wellbeing will help to build momentum towards making it easier to build in timber once these benefits (if identified through this research paper) are made clear. We have also established a lack of understanding as to the make-up of mass timber's contribution to the UK construction industry.

It is often hard to build in mass timber at present in the UK. There are challenges to overcome in building in mass timber compared to traditional systems. We have concerns that given this context, when the industry challenges are overcome and mass timber is successfully used, there is a risk of automatically thinking we have achieved a 'good enough' outcome. There is a further risk of then not scrutinising how mass timber has been implemented and whether things could be even better. Ensuring that we are building efficiently and maximising the best aspects of this construction system is important. Through measurement we feel that we can start to define what good looks like for mass timber and where the challenges are in implementing the best outcomes for people and for planet.

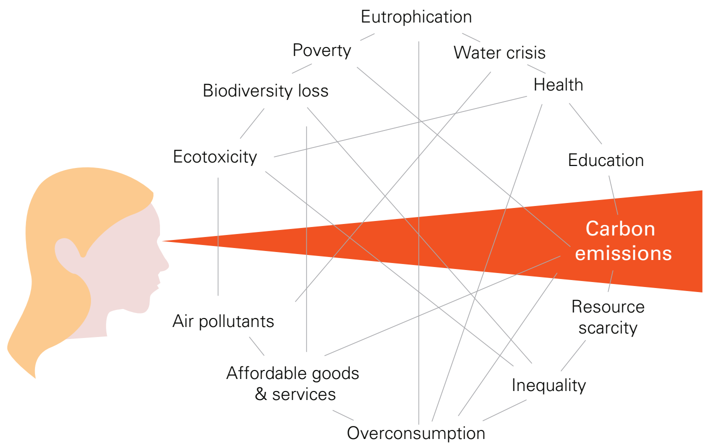


Figure 13. Carbon Tunnel Vision (after Jan Konietzko 2021)

Research team & stakeholders

Research team

The research team was led by dRMM, with funding awarded by Built by Nature in Summer 2022. This section of the report gives a little more information about the relevant experiences of the key stakeholders and why the research team was formed.

dRMM
dRMM is a London and Berlin based, international collaborative studio of architects and designers founded in 1995 by directors Alex de Rijke, Philip Marsh and Sadie Morgan, now joined by co-directors Jonas Lencer, Saskia Lencer and Judith Stichtenoth. dRMM are makers of radical, sustainable and socially useful architecture, recipients of numerous awards including the RIBA Stirling Prize in 2017 for Hastings Pier. Recently completed projects include Maggie's cancer care centre in Oldham; WorkStack light industrial workspace in London; Trafalgar Place housing in London; Wick Lane housing and industrial workspace in London; and Wintringham Primary, a large new timber school in Cambridgeshire.

dRMM is a pioneer in the research and development of engineered timber and pre-fabricated materials. Research and advocacy are both hugely important to dRMM's role within the industry as material innovators. We work within knowledge-sharing groups to promote learning around evolving uses of engineered and pre-fabricated materials. We also collaborate with external experts to create new materials, including the world's first hardwood cross laminated timber.

In 2013, we collaborated with AHEC and Arup to develop a hardwood cross-laminated timber (CLT). This collaboration explored the potential for hardwood timber to outperform its softwood counterpart. The result was the invention of a CLT made from American tulipwood. The material displayed outstanding strength and we used the product for our Endless Stair installation, and subsequently to create the world's first permanent hardwood CLT building.

dRMM has been involved in development of theoretical best practice guidance on topics this study explores. Our Head of Sustainability & Regenerative Design Kat Scott was involved in development of industry best practice guidance for embodied carbon and sustainable design, including the LETI Climate Emergency Design Guide, Embodied Carbon Primer, Architects Declare Practice Guide and Regenerative Design Guide, on the Taskforce for the UKGBC's Whole Life Carbon Roadmap. Our Research Lead Finbar Charleson was involved in the development of ACAN's Embodied Carbon report and is a researcher at Hooke Park in timber.

Figure 14. dRMM team celebrating their Stirling Prize win (Photo dRMM)

Figure 15. dRMM's Stirling Prize-winning Hastings' Pier (Photo James Robertshaw)

Figure 16. dRMM's Endless Stair (Photo dRMM)

Quality of Life Foundation
The Quality of Life Foundation helps local communities, professionals and policy makers to plan, design, create and care for homes and neighbourhoods in ways that will benefit people's health and wellbeing in the long term.

We carry out independent research, engage communities, share evidence, and support organisations to implement best practice in their work. We do this because having a decent, affordable home in a safe, well-designed and resilient neighbourhood is the foundation of a happy, healthy life.

Through the Quality of Life Framework, we share research to build the evidence base on the need for a health and wellbeing approach in housing, the barriers that prevent such an approach, and how to overcome those barriers.

We are a UK charity committed to improving people's quality of life by changing the way the housing industry and government acquires, plans, designs, builds and manages homes and neighbourhoods.

Figure 17. Themes in the Quality of Life Framework (QoLF)

Edinburgh Napier University
For many years, Edinburgh Napier has been undertaking groundbreaking, research into homegrown mass timber resource and production in the UK and has developed a global reputation for its research excellence and industry partnerships in investigating and advancing the field of industrialised timber production and offsite construction solutions.

Edinburgh Napier University has been leading pioneering research into industrialised timber and offsite construction solutions and is host to Built Environment – Smarter Transformation (BE-ST). With Innovate UK funding, the research track record of ENU and the mission of BE-ST to future-proof the commercial and environmental road forward for the construction sector was brought together with key industry partners Ecosystem Technologies; and the University of Edinburgh to test and validate an approach and positive movement towards mass timber production in the UK.

At the start of this project journey, Building Research Solutions were appointed, through ENU, as the whole life carbon consultant. In October 2023, Building Research Solutions merged with **Okana Global** to form their Sustainability Team; we maintain our commitment to providing scientific-rich solutions with academic rigour for the whole construction sector throughout every life cycle stage. Okana is a pioneering global built environment consultancy, placing visionary thinking alongside economic viability. We turn innovative ideas into sustainable realities that resonate with communities worldwide. Within the Sustainability Team, we use data-driven expertise to reduce the environmental impact and deliver actionable solutions. Our leading approach in environmental stewardship drives projects beyond sustainability standards, ensuring a healthier environment for all. Our approach focusses on operational energy, embodied and whole life carbon, indoor and outdoor environments and the creation of sustainable communities. We provide specialist services in human factors, computational assessments, and in situ measurements.

https://innovationhub.napier.ac.uk/environments/environments-case-study-transforming-timber

Funder

BUILT BY NATURE

With additional in-kind funding from the Research team and wider stakeholders.

Research team

Quality of Life Foundation

Edinburgh Napier University

Supported by:

Okana
Let's shape tomorrow

Expert stakeholder advisory group

Landsec

HOARE LEA

Tampere University

TIMBER DEVELOPMENT UK

ARUP

ENGENUITI

RIBA

ASBP

Project participants

Abbey Wood Station Fereday Pollard	**Cambridge Central Mosque** Marks Barfield Architects	**6 Orsman Road** Waugh Thistleton Architects	**Peckham Rye Apartments** Tikari Works	**Sutton Harris Academy** Architype

Project communities

• Station staff • Line and station operators • Passengers	• Mosque staff • Mosque worshippers and community	• Building owner/ managers • Security team • Building occupants	• Residents - including tenants and homeowners	• School staff (inc. maintenance team) • Students

Figure 18. Main project stakeholder groups

Wider stakeholders

Project participants

Through the study selection process, we engaged various stakeholders for each of the buildings. These included:

- Architects: Architype, Fereday Pollard, Marks Barfield Architects, Tikari Works, Waugh Thistleton Architects
- Building owners and building asset managers
- Occupants, residents, tenants and visitors to the buildings who we engaged with during the quality of life component (over 110 individuals)

This network of individuals have all given their time to support the project in-kind and for that we are thankful. We hope that their experiences in participating in this research project will have been informative and that the findings have helped them to make the case for building more best practice mass timber buildings.

Expert Stakeholder Advisory Group (ESAG)

For the purpose of this study we have invited a number of industry experts from a range of backgrounds to support the study through sharing their feedback on the work we have undertaken. We sought to ensure the ESAG covered all the aspects of interconnected research this project would entail.

This panel has been invited at key points through the study process to critique our methods, findings and analysis. This has added rigour to the process as well and widened the perspective to include not only architects and researchers, but developers, engineers and subject matter experts in carbon and quality of life. The ESAG were offered an honorarium for their time, but no ESAG member requested this payment so all their time has been in-kind.

Alexia Laird, Landsec
Andrew Lawrence, Arup
Charlie Law, TDUK
Jane Anderson
Jess Hrivnak, RIBA
Nathan Wheatley, Engenuiti
Dr Paul Hanna, Hoare Lea
Teemu Hirvilammi, Tampere University, Finland

While all of these individuals/organisations were consulted and we have sought to align to their feedback, this report's conclusions and findings may not be endorsed by those we consulted in full. We have sought to incorporate a range of perspectives and come to a balanced position in line with industry best practice.

Funder

Built by Nature is a network and grant-making fund – backed by philanthropic funding - with a mission to accelerate the timber building transformation and a vision for a built environment that works in unison with nature.

Built by Nature supports the built environment sector's pioneering developers, architects and engineers, asset owners and managers, investors and insurers, city leaders, academics, researchers, non-profits, and policymakers in their journey to decarbonise our built environment and protect nature.

The Built by Nature Fund makes grants to the teams and solutions that can increase the uptake of biobased materials and sustainable timber and improve their climate impact, overcoming the most challenging barriers.

https://builtbn.org/

https://knowledge.builtbn.org/

Methodology

2

Methodology

Overview

Our study intent is to develop a methodology for assessing whole life carbon and quality of life together. From mixed method research into how mass timber buildings perform, we have sought to generate a holistic sense of ‘whole life value’.

Our study addresses three main aspects:

- **Whole life carbon** comprising of embodied, biogenic and operational carbon impacts
- **Quality of life** across qualitative (user experience) and quantitative aspects (internal condition monitoring)
- **Project fundamental information** to recognise the role of mass timber within the building’s function, form and technology.

These three aspects map back to the concept of Environmental Social Governance (ESG) - environmental (carbon), social (quality of life) and governance (the underpinning stakeholder needs for each project). To generate an understanding of these three aspects, we have brought together industry best practice methodologies into one integrated assessment and analysis approach. By testing this method on five case studies, we then produced an initial data set where we reflect on how well the method worked and make recommendations for future upscaling of this work.

So, the Methodology part of the report is quite detailed, given that the development of the methodology itself was part of the research project. We have detailed the process we undertook of bringing together these three aspects - that are usually studied in isolation - into one study. We hope others can learn from our experiences and appreciate the position of our recommendations in a wider industry context.

We have needed to bring together at points conflicting, or not always exhaustive, guidelines. We have sought to bridge the gaps between these methods in how we have implemented them. While undertaking this research, best practice has continued evolving rapidly. The construction industry has continued to release further guidelines and there are yet more to follow - important pieces of work that build the context this research sits within. We have done our utmost to keep this study in line with latest guidance, but there are some points where this has not been possible in the constraints of this research project.

Research challenges

- How to determine quality of life as being influenced by mass timber specifically? How do we know it is not just a result from other design features (e.g. window design, ventilation, quality of architecture) or from socio-economic factors (that the residents/building users generally have a higher quality of life due to their own circumstances)?
- How to benchmark/compare/contrast with other building typologies/non-timber construction types without studying examples of these in more detail?
- With our limited sample size, how to generate maximum impact?
- How far should we take the scope of the building performance evaluation with respect to our core research aim?
- How do we allow for this method to be scaled up in the future?

We have sought to address these as far as possible within the confines of the research study, but these themes have continued to crop up throughout and have not been necessarily possible to resolve.

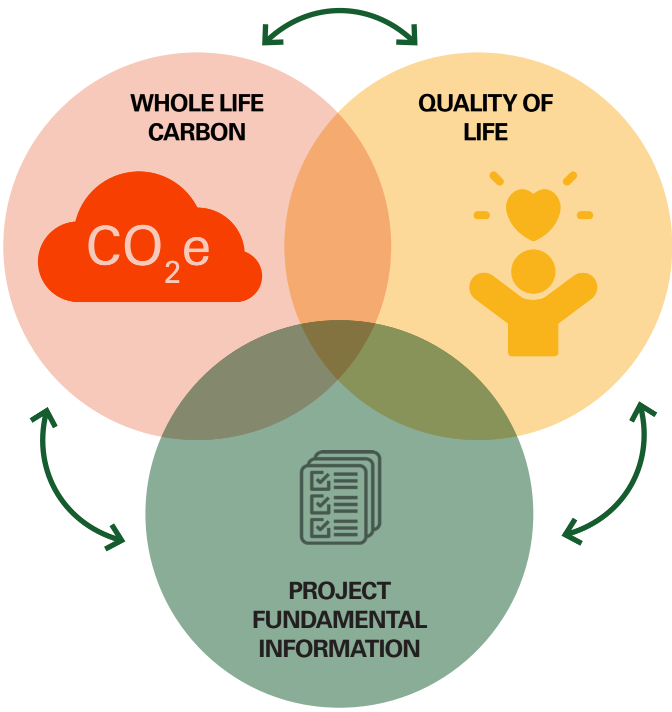


Figure 19. The project’s three main areas of focus

Practice-based research

This research is positioned as ‘practice-based research’ meaning that it sits in the interface between industry and academia. We have written this report for a wide range of stakeholders, from architects and design consultants to policy makers and those with influence in commissioning buildings.

This means that whilst this report is intended to be rigorous and have integrity, it is written to be more accessible and give more foundational background than would be found in an academic paper.

Plenty of collaborative practice-based research in recent years has started to blur the lines between industry and academia. Research team members of this report have been part of developing LETI and Architects Declare industry-facing guidance. The construction industry generates a lot of research-type material that does not always face much scrutiny prior to publication, or parties ‘marking their own homework’ and releasing data that upon closer inspection doesn’t align to industry best practice. Without mechanisms for third party auditing or external assurance of quality in industry, this all creates a sense of not being entirely sure which data can be relied upon. We feel that auditing and more assurance processes for quality of research and impact-relating data in particular is needed to increase the arguments for change that rely on this data - e.g. when arguing timber offers a decarbonisation solution, we need to have confidence in the datasets that evidence this.

On this project, quality assurance has been a key priority, addressed in part by foundation of our Expert Stakeholder Advisory Group and ensuring a collaboration with industry experts. We also engaged with Flora Samuel, lead of the UK practice-based research group at an early juncture to ensure our work was in line with industry best practice and to better understand the role of practice-based research as a valid and useful endeavour, albeit with its challenges.

Risk of bias

While this project has been developed with a view to supporting the uptake of mass timber construction more widely, we have wanted to avoid biases in our analysis of the case study cohort. We have sought to be fair in our appraisal of the positives, as well as limitations, of mass timber.

The key ways we have addressed bias in the research team has been as follows:

- Not measuring our own buildings - allowing neutrality in our appraisal of each case study.
- Following industry standard methodologies for as much of the research as possible (although we have found gaps/bridging challenges with these). Benchmarking data against best practice/industry datasets as far as possible to a common baseline of what ‘good performance’ looks like.
- Being clear about the methodology adopted and its limitations/areas for improvement in the future. Referencing written accompanying discussion and definitions of key terms as far as possible.
- Additional scrutiny via our ESAG, experts and collaborating partners.
- Sharing our dataset as open-sourced information so that others can interrogate our analysis and form their own conclusions.

Figure 20. Examples of industry-developed guidance by LETI and AD

Key takeaways

We see a beneficial role of practice-based research. Those undertaking it should however be considerate of the limitations of this work and seek to develop appropriate quality assurance processes.

Project Selection

We sought to conduct a fair and thorough, albeit rapid, project selection process to choose five case studies for research. As part of this, we needed to make a case for participating in this study and build trust with the relevant stakeholders that this would be mutually worthwhile.

In order to conduct the analysis as thoroughly as we could for each of the projects and to road-test the method fully, we decided that an initial dataset of five projects would be sufficient. The intention is that then in the future we will find a way to upscale this study. Whilst our methodology should be able to apply to most projects, the case studies we have selected have influenced how we have applied and tested that method. It was our intention to achieve maximum impact with the small case study cohort, to really push the methodology to the limits, as well as to hopefully generate useful insights from this relatively small dataset.

There is no full database of UK mass timber projects. The key resources we used as best available datasets were:

- The Wood Awards registry
- Asking for interested parties to contact us for consideration as a participant
- Asking our teams for recommendations of relevant mass timber projects

We compiled a longlist of projects, then reviewed this against a number of factors (right) to inform decision making. We had a shortlist of nine possible schemes. We then approached stakeholders for each of these to enquire about their interest in participating in the project and to learn more. From this, we then had a review with the research team to decide upon our final five case study projects.

Key takeaways

Within our cohort of five mass timber buildings we have managed to address a reasonably wide range of variables. We hope to scale up the dataset in the future, with new case studies particularly sought to target gaps in building typologies not yet covered, to explore examples with encapsulation of timber and to consider reuse/retrofit to make findings more representative and impactful.

Factors	Why this informed our decision making process
Location	We found through the selection process that there was a lack of mapping available to know where timber buildings were in the UK, as well as the scale and typology of what is built where. In addition, we found a hotspot of London and the SE. This was considered likely as a result of the cost of mass timber systems being justified where land values are higher.
Range of architects	We endeavoured to work with a range of architecture practices, so as to maximise on the sharing of knowledge as well as to understand the maturity of this sort of work across practice types in industry.
Type of building function	We wanted to test the methodology application against a range of typologies (building types) in order to see whether any challenges arose in different building settings. For instance, the quality of life component would differ considerably depending on the building type and how people use it, whether they live there, work there, pass through/by it etc. How to survey and interview relevant parties will vary according to typology too.
Scale of building, form	To see how the method needs to adapt/whether it works across a range of building sizes and form types.
Type of mass timber system	To see if there would be any difference in application of the methodology or findings arising from the spectrum of engineered timber products on the market. All buildings would be required for mass timber to be their primary structure. We wanted to secure case studies from a range of mass timber construction methods, however the market dominance of CLT as a mass timber system means that this is the majority of what we have studied.
Completion date	We have selected projects with similar construction dates, post-2019. This would mean projects that were constructed two years after Grenfell fire (2017) and only three years before this research study started (Summer 2022) so buildings would still feel relatively recent. We wanted to ensure that the buildings were following as similar as feasible the regulations and warranty contexts to one another, so that our findings could be as relevant as possible to wider industry. For instance, fabric performance and fire considerations have changed considerably in the past ten years, leading to enhanced requirements which would have an impact on material use for construction.
New-building vs retrofit	The study was interested in looking at new build construction, rather than adaptive reuse. There are increasingly examples of mass timber extensions to existing buildings, and so future wider datasets would benefit from the inclusion of these building types. The methodology would need to be amended to allow a before/after comparison in terms of Quality of Life and to benchmark with a different set of parameters, e.g. likely no or little foundations introduced.
Exposed vs encapsulated timber	We explored the potential of studying mass timber buildings whose timber was fully encapsulated. We decided that this was not necessary for this project to consider, but it would certainly be good to explore in future wider cohorts. How would quality of life for instance be affected by covering up mass timber structure for fire/other reasons? How does encapsulation contribute to the carbon impact of mass timber structures as compared to other systems not requiring encapsulation for fire?

To be explored further

A research project could be to undertake a fuller stock modelling/mapping of (mass) timber construction in the UK. It would be useful to develop a full UK existing built environment asset registry to outline what buildings are made of and how they perform to support the targeting of future retrofits. This would also help to know what our built environment assets may offer to the circular economy and to support a wider range of research projects, like MMT.

Selected case study cohort

The five case studies we have applied the MMT method to are listed in the table below. We feel that across the range of factors we wanted to address with the limited cohort that we have achieved reasonable balance. The geographical spread is not as varied as we would have liked, although this is likely reflective of the London-dominant market for mass timber in the UK to date.

We also have mapped this cohort against the range of mass timber building case studies on TDUK's website and found a good degree of alignment (see right), with the largest mass timber building types covered, and only Healthcare and Restoration/Reuse missing as typologies. In the future we would like to see growth of case study data being developed to be more representative of the UK market.

To be explored further

We have not incorporated any projects where mass timber is fully encapsulated, nor any retrofit, reuse or healthcare schemes. Building a wider case study cohort in the future would be interesting to see the role of encapsulation of timber (for fire and acoustics) on both carbon and quality of life. It would also be interesting to see how mass timber is used in reuse/retrofit projects, e.g. Opptoppen schemes, however this added an additional layer of complexity in surveying/monitoring for this project to cover in its scope.

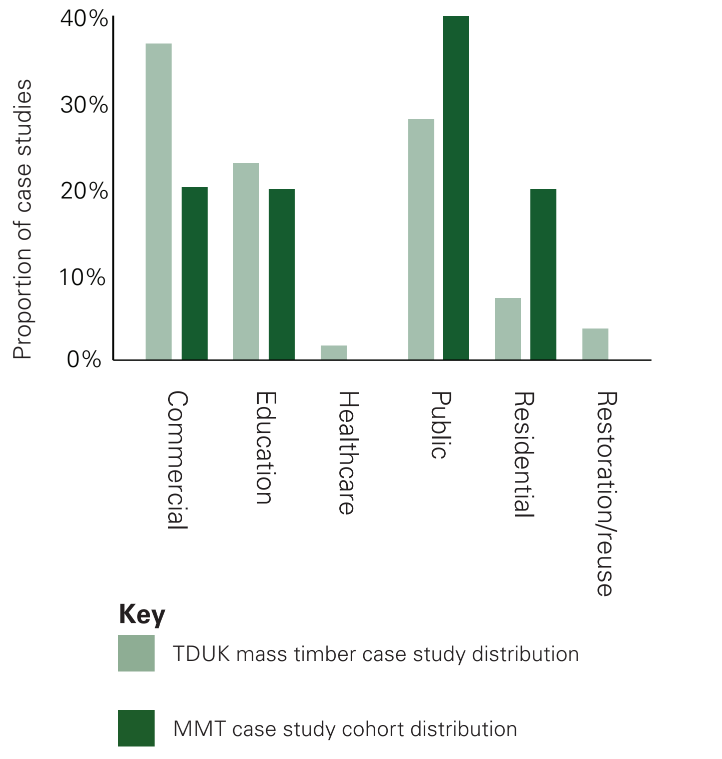


Figure 21. TDUK & MMT project types comparison based on available TDUK case studies in October 2024

Factors	Abbey Wood Station	Cambridge Central Mosque	6 Orsman Road	Peckham Rye Apartments	Sutton Harris Academy
					
Location	South-east London, UK	Cambridge, UK	North-east London, UK	South-east London, UK	South-west London, UK
Range of architects	Fereday Pollard is an architectural and landscape design practice experienced in leading large schemes, including transport infrastructure projects.	Marks Barfield is a female-led practice who care profoundly about the climate and biodiversity crises. They have designed a limited number of mass timber schemes.	Waugh Thistleton is a leader in engineered timber who have delivered mass timber schemes across a wide range of typologies. They also conduct research.	Tikari Works is an architecture & construction studio established in London. Unusually, the studio weaves together architecture, design, construction, and property development.	Architype is the UK's leading Passivhaus architects. They work across studios in Edinburgh, Hereford and London. They are the largest studio of the cohort.
Type of building function	Transport infrastructure	Religious/civic	Commercial workspace	Residential	Education
Scale of building, form	A two-level station with stingray like curved roof form.	Mostly across one storey, with mezzanine and basement. Intersecting volumes in plan/section.	Five-storey building with a rectangular plan form.	Two rectangular buildings with pitched roof form, duplex homes within.	A large, multi-storey school set out over a stepped plan.
Type of mass timber system	GLT beams with CLT deck roof.	CLT external walls, intermediate floors, columns and GLT roof structure.	CLT intermediate floors, core and roof structure. In direct hybrid wth steel.	CLT/GLT external walls, internal walls, intermediate floors, roofs and core.	CLT/GLT corridor walls, some external walls, floors (first, second, third floors), and roof.
Completion date	2018-20	2020	2020	2020	2019
New building vs retrofit	New building	New building	New buidling	New building	New building
Exposed vs encapsulated	Exposed	Exposed GLT. CLT walls painted white.	Exposed	Exposed	Exposed

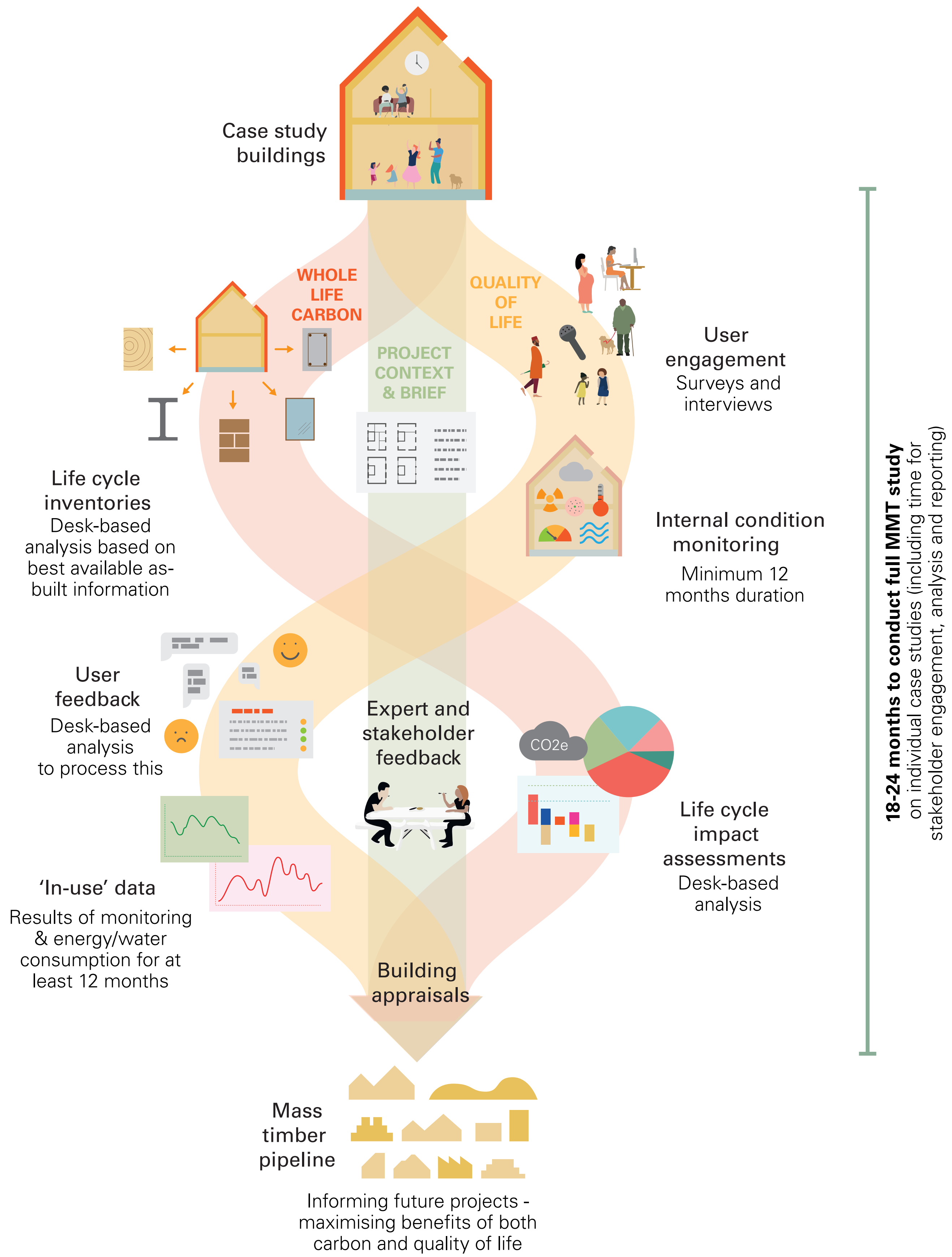


Figure 22. The report methodology illustrated

The assessment method

This research project could be described as 'mixed-method' due to the combination of qualitative and quantitative research approaches. As with any research method, this approach presents advantages and disadvantages.

Bringing together qualitative and quantitative evidence was necessary to answer the research question, with a variety of evidence types needed to explore each of the disparate study elements. How do we then bring these different modes of enquiry together in a singular study? And how can we fairly represent a range of evidence types to form useful conclusions across the whole?

While this project has been intended as a holistic undertaking, the task of conducting the research has been granular. The method requires the study to be broken down into sub-components. These were:

Whole life carbon:

- Building material/product inventory. Environmental Product Declarations collated alongside supporting data.
- Life cycle impact assessments based upon the inventory to formulate embodied carbon, biogenic carbon and whole life carbon information.
- Energy use and water use calculations to contribute to operational water and energy use for the WLC calculation and to separately benchmark against energy use intensity targets.

Quality of life:

- Building visits in-person and online engagement to collate user experience responses to a survey (qualitative data).
- Internal condition monitoring of the buildings to measure quantitatively how they perform against best practice recommendations.

Project fundamental information:

- Gathering key project information to understand the project parameters, priorities and reasons for adopting a mass timber system to contextualise our other research.
- Photographs, plans and additional supporting visual information

The different aspects of the study were run relatively concurrently, which means that we did not use the in-person qualitative aspects to scrutinise findings of our in-use building monitoring data findings in any further detail. There is then a relative neutrality between data types, but also a lack of ability to dig deeper in a sequential way - zooming into issues identified in one component in the next. We intended that no one aspect of the study takes priority over another and that the findings are presented as evenly as possible in this report.

How long does this method take?

The MMT research project ran from Summer 2022 to Autumn 2024. We would recommend others seeking to apply the MMT method to other case studies allow 18-24 months for a full process from start to finish, although it should be possible to deliver on a faster turnaround of 15 months if stakeholders are very engaged and where access to the building for monitoring is straightforward. This 18-24 months includes:

- c. 3 months stakeholder engagement and securing relevant permissions for conducting the study, following best practice for ethics and safeguarding. Allow time for a market review of monitoring devices and defining the building specific study parameters/objectives.
- 12+ month monioring period for internal condition monitors and energy/water use data to be collated. This period may take even longer if there are any data gaps in the monitoring period.
- While the 12 month monitoring period is underway, the desk-based WLC related activities can be conducted alongside any wider research.
- c. 3-6 months for analysis of findings, reporting and engaging with stakeholders. Allow time in this period for a data/analysis quality review by a suitable third party to ensure quality.

You could streamline this further by reducing in-building monitoring to a 9-month period, however we would really recommend observing the full 12-month monitoring cycle (see BS EN 40101 for best practice on monitoring periods).

Key takeaways

The research project is mixed-mode covering a range of qualitative and quantitative aspects. This helps our findings to give a holistic impression of performance in terms of whole life carbon and quality of life. Managing these multiple strands of research inquiry simultaneously requires careful management.

BPE level and category	Parameter	Preliminary	Light	Standard	Inc. in the MMT method?	Notes
Building parameters	Building type, location, description and purpose	Y	Y	Y	Y	This information is, where included, within the 'project fundamentals'. In each case study, this is presented in the first double-page spread.
	GIA	Y	Y	Y	Y	
	Floor plan	N	Y	Y	Y	
	Building occupancy (actual and design)	Design only	Y	Y	Y	EPCs and DECs were sought where relevant to inform our WLC study but are not included in this report as this is not the primary objective of this research project.
	Attachment, orientation and construction (description)	Y	Y	Y	Y	
	Building services (description)	Y	Y	Y	Y	Design targets are referenced to some extent in discussion and fundamentals for each project, however we have kept this light to keep the study remit tightly bound to our interest in decarbonisation and quality of life potential of mass timber.
	Energy performance certificate (where available)/ Display energy certificate (where available)	Y	Y	Y	Where relevant	
	Design targets (all available and relevant)	Y	Y	Y	Where relevant	
Occupant/user experience	Occupant comfort satisfaction, wellbeing, needs and usability assessment	Y	Y	Y	Y	**Investigative element**. Here we have gone beyond the baseline established in BS EN 40101.
	Building/facility manager assessment (where present)	Y	Y	Y		We met many building managers and listened to their feedback, but this was not core to our study.
Post-construction review	Air permeability tests	N	N	Y		These aspects were not considered as they do not strongly relate to our study's focus and are relatively onerous to undertake. Acoustics/soundscape was covered to an extent in user surveying.
	Commissioning/servicing review	N		Y		
	Acoustics/soundscape review	N		Y		
	Handover, induction and user experience review (where available)	N		Y		
	Maintenance information and procedures review (where available)	N		Y		
	Design, construction, procurement and delivery details (where available)	N		Y		
	Building walk-through	N		Y	Where relevant	We did of course walk-through all five buildings. But we did not record our experiences nor the detail on the building fabric condition as that was not core to our study's area of interest.
	Controls review	N	N	Y		These aspects were not considered as they do not strongly relate to our study's focus and are relatively onerous to undertake.
	Thermal imaging survey (winter)	N	N	Y		
Energy use and generation	Annual meter readings (12 months)	Y	Y	Y	Y	We used as much meter data as was made available to us, and where possible more frequent BMS recordings.
	Consumption and generation monitoring (30 min, 12 months)	N	N	Y	Y	
Water use	Annual meter readings (12 months)	N		Y	Y	
Internal condition monitoring	Temperature and relative humidity (30 min, 12 months)	N	Y	Y	Y	**Investigative element**. Here we have gone beyond the baseline by also looking at tVOCs. However Airthings devices used did not monitor at the exact frequency BS EN 40101 asks for.
	CO2 (30 min, 12 months)	N	N	Y	Y	
	Existing sources (temp, RH)	N	Y	Y	Where relevant	We used external sources - see method for more.
	Onsite temperature and relative humidity (30 min, 12 months)	N	N	Y	N	

Figure 23. A simplified and extended table from BS EN 40101 summarising the scope of potential BPE activities.

A building performance evaluation (BPE)

The methodology can be described as a building performance evaluation. This method is for a range of scopes of analysis of completed buildings in occupation.

At the time of developing the research project for grant application the best available guidance for undertaking post occupancy evaluations was the RIBA's POE Primer. However, BS EN 40101 '*Building performance evaluation of occupied and operational buildings (using data gathered from tests, measurements, observation and user experience) - Specification*' was released during our grant application phase. We have endeavoured to follow as much of this standard as possible. We have done so while being considerate to the core intent of this study's remit and reporting intentions

Of BS EN 40101's range of activities suggested, those aspects we have covered are outlined in the table shown (left). Our study is specifically interested in the role of mass timber in contributing to carbon and to quality of life. We did not therefore undertake the fullest spectrum of POE/BPE work, as this would have taken us beyond our core focus into the realm of other questions (e.g. how well commissioned and established is the building management system? How much do people like the building layout? And so on).

We found BS EN 40101 to be a helpful framework and basis for much of the study, with great alignment with much of our research scope. Some aspects of the BPE preliminary/light scope are required in any case in order to undertake a Whole Life Carbon/Life Cycle Assessment (water use and energy use). And some aspects form the beginnings of our Quality of Life research component. There is a notable lack of embodied and whole life carbon in the current BS EN 40101 framework. In addition, the standard does not cover all typologies in equal depth, so we found some implementation challenges in applying its recommendations to the spectrum of projects we assessed.

The MMT project focus on whole life carbon (beyond BS EN 40101) and quality of life are interpreted as 'investigative BPE elements', while our wider fundamental project information component closely aligns to the rest of the 'preliminary' BPE scope, with enhancements in relevant areas. One key practical consideration was for the internal condition monitoring to be undertaken for a sufficient time period (12 months is optimal). This is a major consideration for conducting BPEs.

Figure 24. BS EN 40101

Key takeaways

Building Performance Evaluations now have a standard framework. This supports consistent, replicable approaches to undertaking this type of work across a range of building types, to varying degrees of depth of study. We would encourage others to use this and collectively refine the standard over time.

Post Occupancy Evaluation (POE)/ Building Performance Evaluation (BPE)

These terms are used somewhat interchangeably by industry. Building Performance Evaluation (BPE) is our preferred term as a more overarching and better defined term, but we appreciate it is relatively underused as compared to Post Occupancy Evaluation (POE). As set out in BS EN 40101; *'"building performance" can cover all parameters and descriptors that capture how well the building fulfils its purpose. Building performance evaluation is the term used to describe the gathering of quantitative and qualitative data that characterise the performance of a building [...] and the interpretation of these data to draw conclusions regarding specific performance attributes and the overall performance of the building'.*[71]

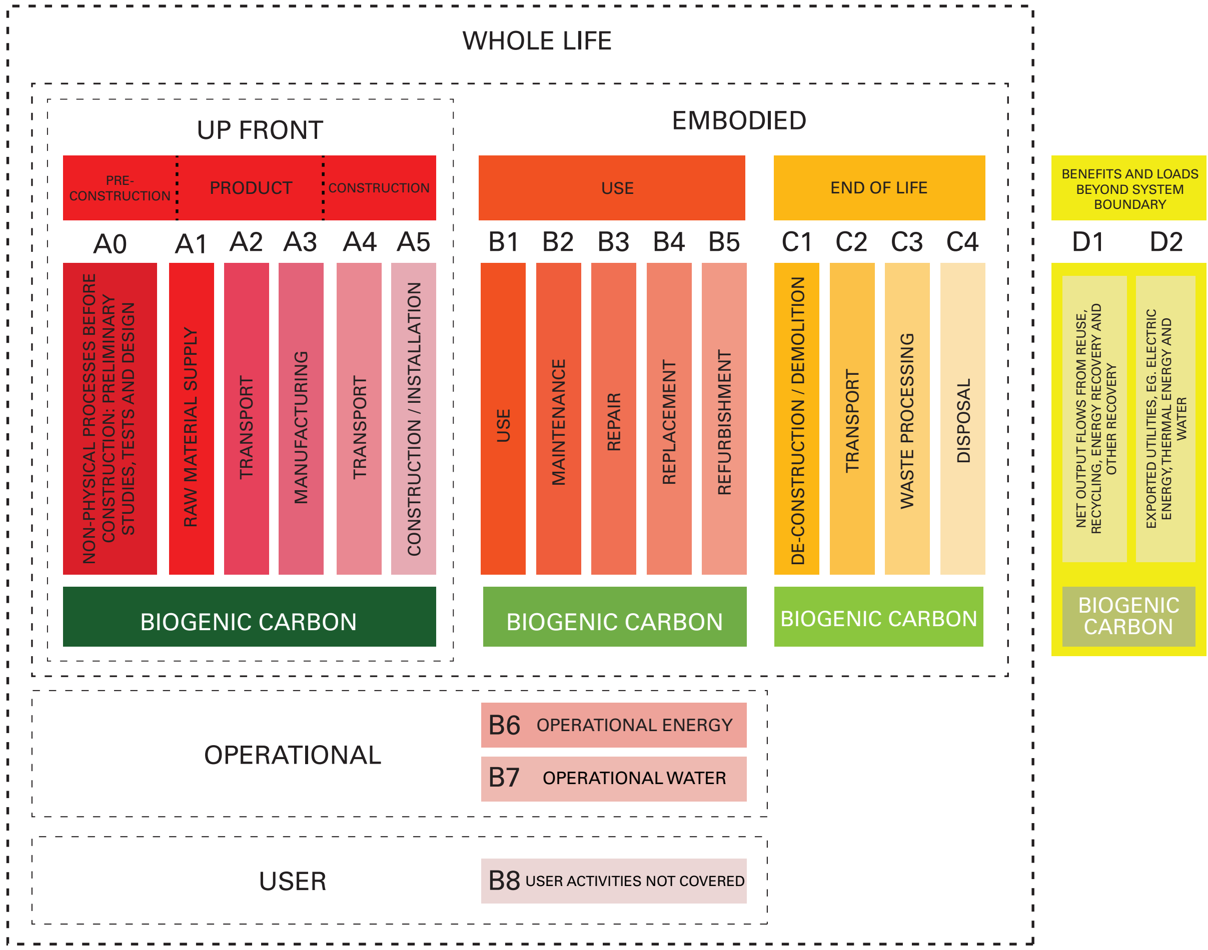


Figure 25. Life cycle stages defined by BS EN 15978:2011 and as defined in RICS

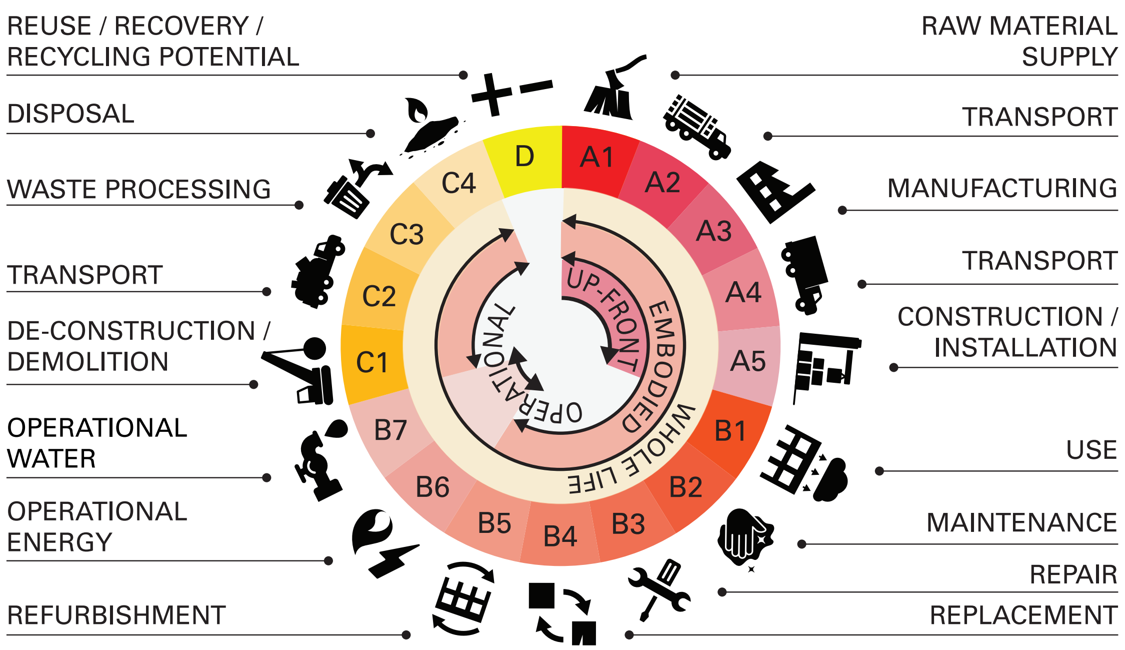


Figure 26. WLC shown in relation to the circular path of a building's lifecycle

Whole Life Carbon

Our study covers the full extent of Whole Life Carbon A-C, inclusive of B6 & B7. This part of the methodology is very well-established and under constant development in industry for best practice approaches. The main work here has been in developing a workflow and ensuring consistent implementation and representation of findings across the five case studies.

There is a well-established methodology for the measurement of whole life carbon in the UK with relatively strong consensus (with some detailed areas under more scrutiny). Measurement of whole life carbon is covered by BS EN 15978 and RICS guidance. The RICS guidance was updated during the late stages of this research project's lifecycle, which means that our study relates to the prior guidance (we have applied v1 rather than v2). In future iterations of this report, we would like to review what the impacts of this update would be and revise our figures accordingly.

This part of the research project method is further broken down into distinct aspects:

1. Embodied carbon (A1-A5, B4, C)
2. Biogenic carbon (A1-A5, B4, C): sequestration and storage
3. Operational carbon (B6 & B7)

We will cover these separately in the following pages.

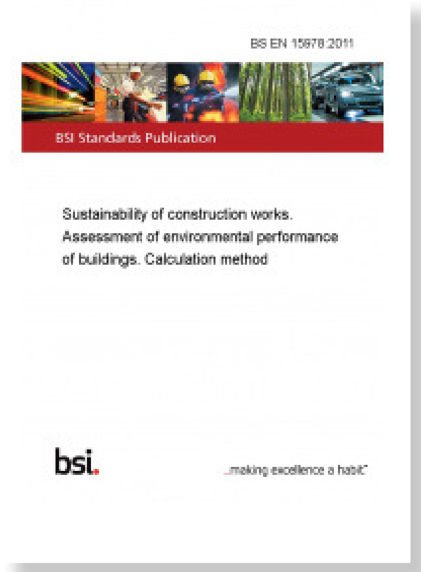


Figure 27. BS EN 15978

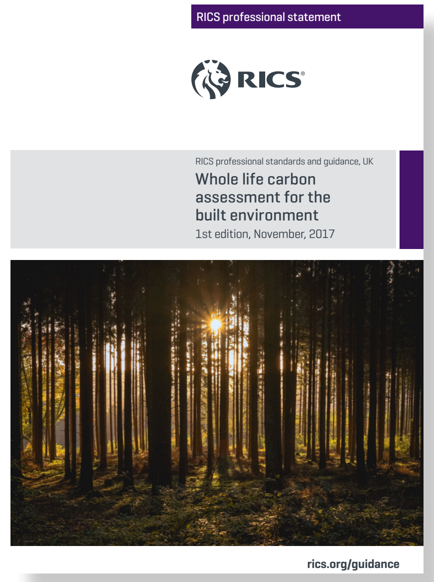


Figure 28. RICS 1st edition of 'Whole life carbon assessment for the built environment

Figure 29. RICS 2nd edition of 'Whole life carbon assessment for the built environment (released in Summer 2024)

Embodied carbon

We are primarily interested in the embodied carbon impact arising from mass timber structure and how this differentiates from other methods of construction by comparing against targets/other buildings in industry. We wanted to have good quality, comparable data from the five case study buildings, to demonstrate a comprehensive level of detail about how mass timber contributes to whole life carbon impact.

Embodied carbon analysis is undertaken through assessment of as-built drawings and quantities information to form a material inventory for each of the building case studies, to which global warming potential can be applied using a range of data sources, and preferably EPDs.

To conduct this study, the following approach was adopted:

- A material inventory was built in Excel. Architects were asked to input as-built quantities data to a spreadsheet, with conversions from architectural units to functional units. These quantities were reviewed and refined to ensure quality of data input, with iterative review and meetings held to run through any gaps in data or clarity.
- Architects were asked to accompany this material inventory with EPDs or as much information as they had about the products used to construct the buildings. This was then used to create a life cycle impact assessment (LCIA) with, as far as possible, GWP data originating from EPDs. If EPDs were not available, then we were as robust as possible with forming a close representation using generic data or from first principles, in line with recommendations.

The scope of this LCA includes a cradle-to-grave analysis (Stage A-C) with an additional assessment of Stage D benefits for each case study. All raw materials and energy inputs related to core, roof, internal partitions, and façade of the functional unit (FU) are included, as far as they are known. MEP and FF&E impacts are estimated based on LETI benchmarks. This is a challenge consistent with those faced more widely by industry at present – there is a lack of EPD availability for MEP and FF&E items. Thus, no cut-off criteria in the direct object of the assessment are applied.

Nevertheless, a number of elements are considered beyond the scope of this LCA study and they are:

- Production of loose (i.e. not fixed) furnishings and fittings required for the use phase, e.g. furniture, lighting, appliances, etc., as they are often excluded from common LCAs of dwellings.
- Supporting functions associated with production, installation, deconstruction, and EoL activities, e.g. staff travelling to work, R&D, product testing, etc.

Some learnings from implementing the embodied carbon methodology:

- One key challenge was translating from architectural quantities to the functional units required for undertaking the carbon assessment.

Embodied carbon

'The embodied carbon emissions of an asset are the total GHG emissions and removals associated with materials and construction processes, throughout the whole life cycle of an asset (modules A0–A5, B1–B5, C1–C4, with A0 assumed to be zero for buildings).' [73]

Life cycle inventory

This is the total recorded materials/products and quantities used to construct the building. This forms the basis of the whole life carbon assessment, which when combined with the relevant GWP arising from EPD data (and in the absence of this, the use of best practice recommendations including the use of generic data and rules-of-thumb) allows a calculation to be undertaken to appraise the carbon impact of the whole building.

Environmental Product Declaration

'A document that clearly shows the environmental performance or impact of any product or material over its lifetime.'

Data representation

To try to portray the data as accessibly as possible while sharing enough information to allow industry benchmarking we have adopted a range of methods:

- A high-level summary table with stage-by-stage data for carbon (by GIA and in total) with biogenic carbon reported as per best practice (see next section covering this in-depth).
- Benchmarking against LETI/RIBA/NZCBS best practice for embodied carbon, taking into account the different scopes of assessment for these.
- Snapshots for the material, biogenic carbon and stage-by-stage breakdowns for each building.

We believe this range of graphical and numerical outputs fairly presents the majority of useful information the assessment process has produced, aligning to best practice for biogenic carbon reporting in particular.

We have sought to align our charts with those used in other guidance documents, for instance the pie charts and material bar charts are similarly used in LETI's Embodied Carbon Primer. For benchmarking, we have developed our own visual method to represent the huge array (in some typologies) of benchmarks and limits currently available. We hope that in the future more standard means for representing will become more widespread, for instance the LETI carbon rating now needs to be aligned with the NZCBS to be useful.

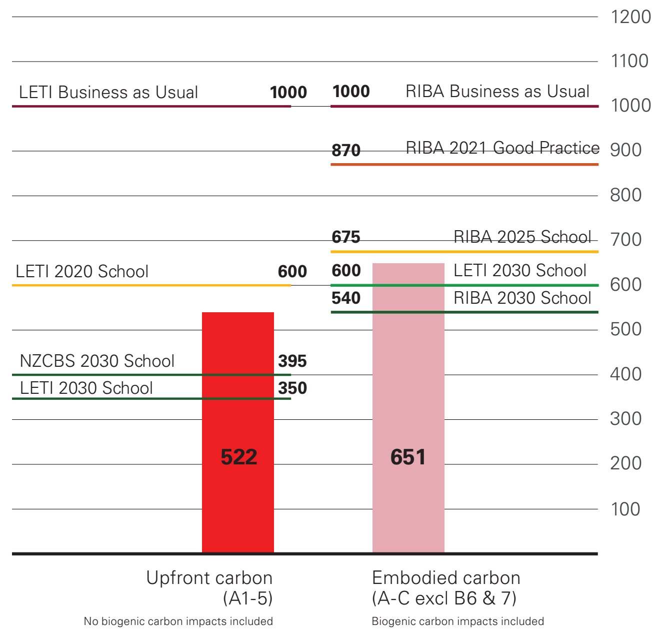


Figure 30. An example of how we have shown benchmarking for each building (where benchmarks exist).

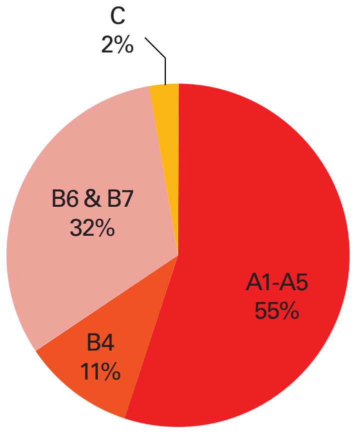


Figure 31. Pie charts break down impacts aligned to LETI Embodied Carbon Primer

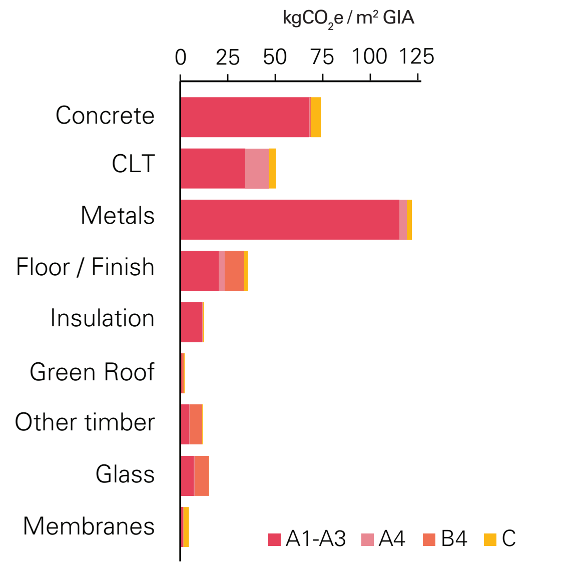


Figure 32. Materials' impacts are disaggregated into broad families, across the life cycle stages

Biogenic carbon, sequestration and storage

In practice, biogenic carbon is reported in a variety of ways. This is a key challenge to addressing critics of timber's carbon potential, as the inconsistent implementation of this component is weakening the case for timber's decarbonisation potential, with detractors not taking *any* carbon analysis for biogenic materials seriously.

At present, best practice is to report biogenic carbon separately when reporting upfront carbon only, and to incorporate in the total for embodied or whole life carbon. (As outlined in definition of Biogenic carbon, right, derived from the latest RICS methodology).

It is impossible at present for a mass timber building to be 'negative carbon' or 'carbon positive' or 'carbon neutral'. This is because there will still be some form of carbon emission associated with the timber production, manufacture, transport and in-use replacements as well as end-of-life. Furthermore, it is important to acknowledge the significant carbon impacts of the wider range of materials and products used elsewhere in the building system (for it is currently impossible to build a totally biogenic building in the UK market, as demonstrated by the case studies this report covers). The only way a building could be hypothetically **'carbon negative'** or **'positive'** today would be if the carbon accounting were to only consider upfront carbon emissions and deduct biogenic stored carbon, which would not be following best practice reporting methods. It is paramount that those reporting carbon impacts associated with mass timber (or any biogenic material) follow best practice guidance to ensure a consistent and level playing field for comparisons and to avoid confusion/greenwash.

It is important to follow best practice guidance to also avoid inadvertent incentivisation for inefficient use of biogenic resources. While naturally renewable, there is a finite quantum of natural resources that can be extracted sustainably from forests/woodlands. Current methods seek to avoid a scenario where non-structurally required CLT is specified to boost the long-term '**carbon storage**' potential of a building in pursuit of exceeding upfront carbon emissions from non-biogenic resource use. This is the main reason that upfront sequestered/biogenic carbon is reported separately - to disincentivise this.

As it would seem there is a wider consensus among timber advocates that current reporting practices do not adequately capture the carbon story and likely lifetime for biogenic carbon storage. We would suggest that alternative mechanisms are reviewed and explored with a view to advocating for change, however this should not be conflated by expressing frustrations with the current standard methodologies in improving rules that detract from best practice on an ad hoc, project by project basis. Inconsistent reporting of carbon relating to timber buildings and misuse of labels such as **'negative carbon'** confuse the wider market and lead to an unfair advantage for those who misuse carbon assessments (e.g. through the deduction of biogenic carbon from upfront). We need to collectively work to a common baseline for any of the decarbonisation impact case for timber to really stand a chance of being taken seriously by industry.

This all also reminds us how critical it is to more generally decarbonise, towards true carbon neutrality/positivity in the future. A holistic approach towards decarbonisation must be adopted, in line with approaches such as the Net Zero Carbon Building Standard (NZCBS). This helps to avoid the overemphasis of the role of any one particular building element/system and to ensure designers and those commissioning buildings seek to align to sustainable design best practice in all design aspects - not only embodied carbon in the building structure, but throughout all elements and also in terms of operational energy/water use. This is why this report has considered whole life carbon as opposed to embodied carbon alone.

How have we applied best practice?

Within this research project, to determine the carbon sequestration potential of the timber elements in each project, this data was either included in the impacts reported in the EPDs or it was calculated following the formula provided in BS EN 16449.

The study follows conventions inferring that carbon must be 'checked-in' at end of Stage C, meaning that it is assumed that the carbon stored in any biogenic material element will be 'transferred' to another product system (e.g. recycled into another timber product) or 'released' back into the atmosphere (e.g. burning for energy production) at end-of-life (60 years in a LCA). Our end-of-life assumptions are relatively conservative as they are derived from EPDs. TDUK's paper 'Assessing the carbon related impacts and benefits of timber in construction products and buildings'[72] is recommended to be followed in analysis of timber-based buildings to ensure the end-of-life scenarios are in line with the UK market as closely as possible.

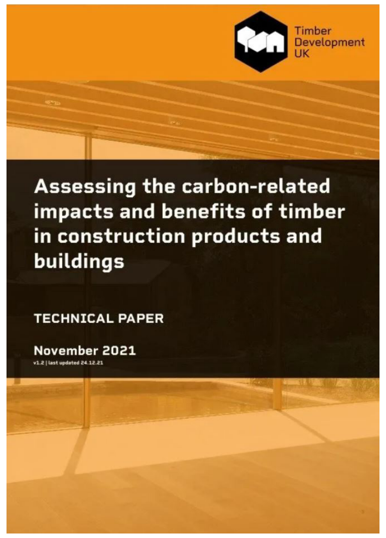


Figure 33. TDUK guidance on carbon measurement

To be explored further

Others have begun to explore refinements that could be made to the whole life carbon method to better explain the biogenic carbon story, particularly in terms of end-of-life. Examples include HTS' white paper 'Does a life cycle carbon assessment constrain the benefits of biogenic materials?' (2023).[77] This explores limitations to current approaches, including considering for circularity.

In the future we would like to explore end-of-life scenarios for the case study buildings further, showing a range of potential outcomes depending on what the end-of-life scenario would be in an alternative carbon accounting system, helping to inform thinking in this area. Is it likely that in 60 years we will allow carbon to be released via combustion of mass timber elements? Will there not be a circular economy for mass timber? And if we do combust mass timber elements, would this be considered an offset to the need to produce biomass pellets, therefore a benefit as compared to business as usual?[78] Will advancements mean these emissions will be captured and stored?

We believe that there is a case for dynamic LCA methods to be implemented in the UK as seen in France (RE2020).[79] It applies dynamically weighted coefficients to the long-term carbon impacts of biogenic materials, i.e. carbon emitted in 50 years is worth less as emission than now, because by being released later we have the opportunity in the intervening 50 years to decarbonise other systems and develop alternative, most likely improved, end-of-life outcomes. This helps to address the weighting of carbon reductions now as being most important, to buy us more time effectively. This concept of the difference between carbon now vs carbon later has been explored more deeply in Arup's paper 'The Time Value of Carbon.'[80]

We did not have capacity in this research project to critique as much as we consider there is a need for industry to do. We do need to be very careful to ensure that any updated mechanisms don't have inadvertent impacts that can result in net-losses of carbon stored in forests and other systems. This area of research warrants more attention.

Biobased materials

'*Bio-based products are wholly or partly derived from materials of biological origin (such as plants, animals, enzymes and microorganisms, including bacteria, fungi and yeast).*'[74] Besides timber, examples of these products in the built environment application include but are not limited to:

- Straw – insulation, structural straw construction
- Hemp – cladding, blocks, hemp-lime
- Bamboo and alternative 'woodish' species
- Mycelium – blocks, etc.

Carbon sequestration

This is the process of capturing carbon dioxide occuring as a result of a range of chemical and physical processes, both natural and human-induced. For instance, plants sequester carbon via photosynthesis, while mineral weathering, concrete carbonation and CCS are all other methods (to varying degrees of success). Beyond plant-based sequestration (e.g. in forests), the oceans and soil offer other sequestration means, as do other species (e.g. phytoplankton).

Carbon storage

Carbon that has been sequestered can be held in storage for varying timespans. Maximising long-life carbon storage helps to extend the period before any re-release of carbon dioxide back into the atmosphere for as long as possible, allowing us more time in the here and now to decarbonise other systems. The potential for biobased materials, including mass timber, to offer long-term carbon storage solutions is much discussed (with limitations/barriers captured earlier in this report). There is yet to be full integration of its storage potential in carbon accounting methodologies in the UK. Further research is needed in this area [75] to ensure estimated storage is genuine and follows best practice to safeguard against re-release.

Biogenic carbon

Biogenic carbon refers to a specifically biobased-originating carbon sequestration, including by photosynthesis. According to RICS v2:

'Carbon removals associated with carbon sequestration into biomass, as well as any emissions associated with this sequestered carbon. Biogenic carbon must be reported separately if reporting only upfront carbon, but should be included in the total if reporting embodied carbon or whole life carbon.'[76]

Operational carbon

Calculation of operational carbon assumes that energy and water use are both constant throughout a building's assumed service life (typically 60 years). Once an estimate for the typical energy and water use is available, then operational carbon is calculated by multiplying the annualised consumption by the years of expected service life and the relevant electricity carbon factor (including or excluding decarbonisation). These carbon factors are calculated and published yearly by the Department for Energy Security and Net Zero (DESNZ). Energy-associated emissions are reported in module B6 while water-related emissions are reported within module B7.

Ideally, it is best to have actual metered data measured during typical occupation and over a period of a year or more. However, this was only the case for three of the projects assessed in this research.

When metered data is lacking, then annual energy and water use must be estimated. Typical starting points for data estimations can be: thermal models (e.g. using the TM54 methodology or PHPP), project documentation (e.g. BRUKL) or even, as a last resort scenario, Energy Performance Certificates (EPCs). All of these are renowned for their lack of predictive power and precision, frequently resulting in "performance gap". Despite this issue, these data sources are easily accessible and are generally available for every project.

In its simplest terms, any of the above-mentioned data sources provide some form of energy and/or water consumption estimate. The estimation precision is going to vary significantly between sources, with metered being the most reliable, while the others, based on multiple assumptions of varying quality, less so. Still, data availability will generally enable straightforward extraction of annualised energy/water consumption figures for any building. From those energy/water consumption estimates, conversion into whole life carbon is achieved by multiplying it by a relevant carbon emissions factor and the building's assumed service life.

For both water and gas, it is reasonable to consider constant emissions factor throughout the life cycle. Burning natural gas should result in similar GHG emissions now or in 60 years' time. However, with a quickly decarbonising national electricity grid, accelerated by global and local policies for economy decarbonisation, it would be unrealistic to assume same for electricity's emissions factor. The Electricity System Operator (ESO) has modelled several scenarios for electricity decarbonisation (Future Electricity Scenarios, or FES), with the less optimistic of those being the "Falling Short" scenario. In this scenario, the UK fails to meet its 2050 net-zero targets, but electricity still significantly decarbonises before then (just not enough). As standard practice, operational emissions for electricity consumption assuming both non-decarbonised grid (i.e. same emissions factor as at project completion) and decarbonised (i.e., considering an average emissions factor for electricity to 2050 based on ESO's "Falling Short" scenario) are calculated. The former tend to be about nine times larger than the latter. For the overall whole life carbon assessments we chose to use the decarbonised results, as they're more likely to be representative of future reality.

In reporting the operational carbon data, we have adopted the industry current preferred dual approach. We have declared both the Energy Use Intensity estimated or evidenced by metered data for each building, then also incorporated within our WLC assessment within B6/B7.

Building	Data source for EUI/operational carbon analysis
Abbey Wood Station	Based on BRUKL estimates for energy and water use
Cambridge Central Mosque	Based on two years of metered data
6 Orsman Road	Based on one year of metered data
Peckham Rye Apartments	Based on freely available EPC data
Sutton Harris Academy	Based on one year of metered data

Energy Use Intensity (EUI)

The total amount of energy (kWh) used in a building in a year divided by its floor area.

Therefore EUI incorporates both regulated (as covered by UK Building Regulations) and unregulated loads. Actual energy use consumption data is needed to derive a building's EUI.

Benchmarking

It is only through benchmarking that we are able to understand the relative impact of buildings and gauge how 'good' they are in relation to business as usual/best practice.

A recurring comment in stakeholder engagement on this project has been whether we can benchmark our case studies against non-timber building examples. We do not believe this to be a fair enterprise, as the embodied carbon impacts of each of our five case studies arises out of the project brief, site and other specific natures of their circumstances. Finding close comparators would not be necessarily possible, and trying to retrospectively 'design' a concrete/steel structure would not be sensible, as the building system of choice is so engrained in the early design stages - we cannot possibly replicate the design process for an alternative system with the same rigours.

Therefore the buildings are benchmarked for whole life carbon against LETI Embodied Carbon rating system, RIBA 2030 Climate Challenge and the Net Zero Carbon Building Standard pilot, as the best available UK benchmarking options. There are gaps where these do not have typologies covered for all five of our case studies. If it has not been possible to find a close comparator then we have not benchmarked. This area is one we would like to revisit in the future as more targets and limits emerge. We have not fully covered all of the aspects the NZCBS covers in its benchmarking/limits requirements, so in future versions of this dataset we would seek to further align to the total metric base this asks for.

It is also important to note that all five of these buildings were designed and constructed in advance of all these embodied carbon and whole life carbon benchmarks becoming available. Performance against these benchmarks should not therefore be viewed as what best practice looked like when the buildings were designed, but rather for additional context to understand their carbon impacts in relation to our decarbonisation pathways.

These benchmarking sources did not cover all five of our case studies however, with infrastructure not covered at present and with worship buildings less well established and only one benchmarking source available (NZCBS). As more data is shared widely in industry via the NZCBS pilot and through the Built Environment Carbon Database (BECD) and local authorities' planning requirements in places like London, we expect to be able to improve the benchmarking detail and granularity in the future.

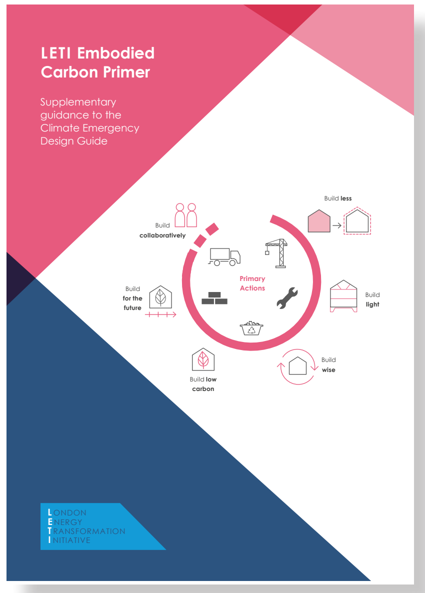


Figure 34. LETI Embodied Carbon Primer (2020)

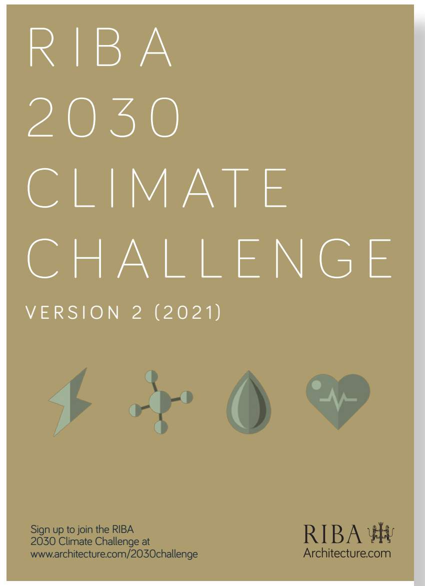


Figure 35. RIBA 2030 Climate Challenge v2 (2021)

Figure 36. UK NZCBS (2024)

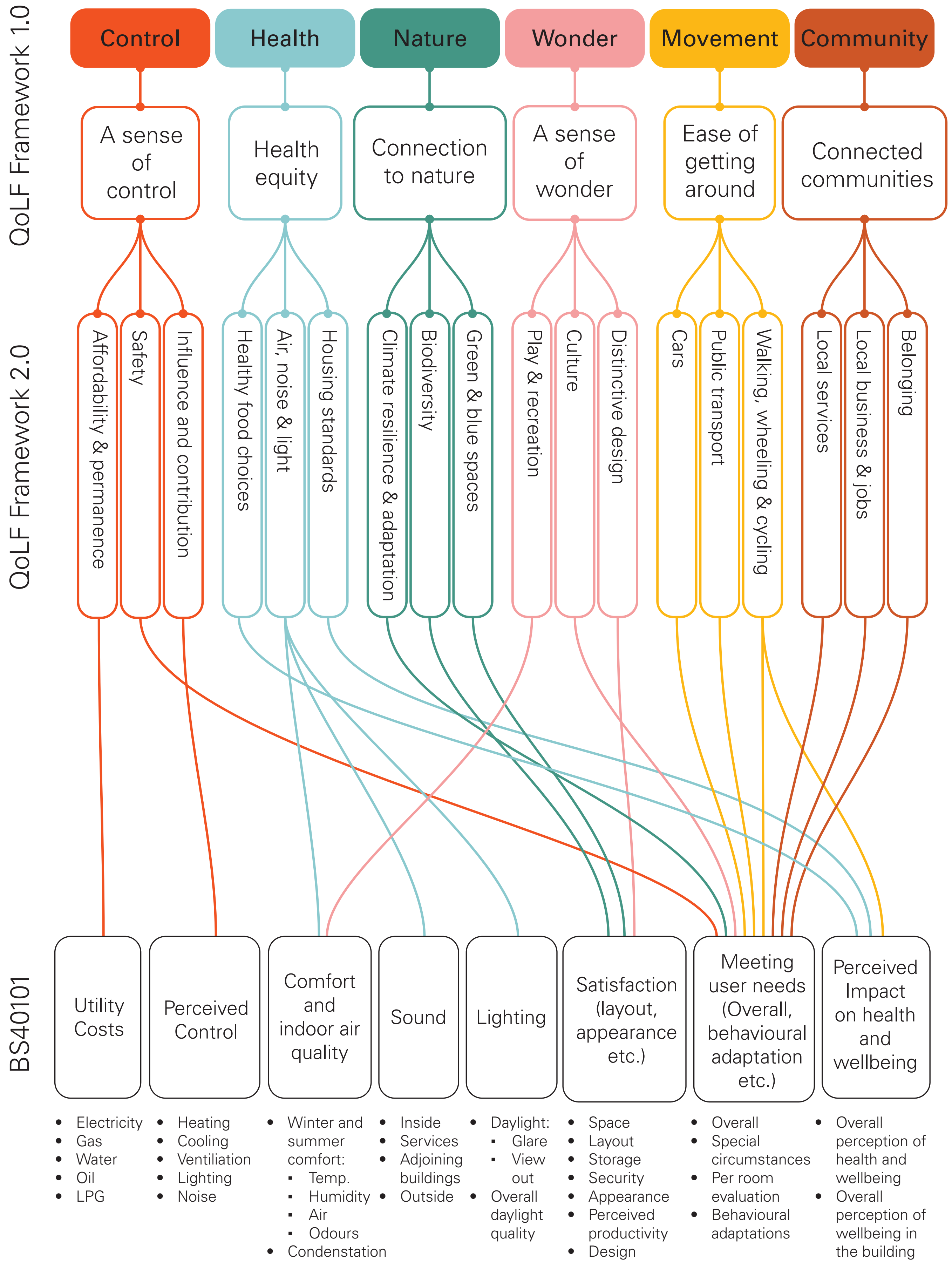


Figure 37. QoLF Framework and BS EN 40101 overlay

Quality of life

As has been already established, quality of life is more of an emerging area of interest for the industry, and society in general. Guidance is therefore more mixed in its quality and consistency in application as compared to the more established whole life carbon aspect.

We are primarily interested in the impact of mass timber on quality of life. This was studied in two main ways:

- Occupant satisfaction/experiences
- Internal condition monitoring

In-person research activities were required for both aspects. Engaging with building stakeholders was more critical here than for the desk-based WLC assessment.

Occupant satisfaction/user experience

As has been outlined, the Quality of Life Foundation has defined six themes that contribute to quality of life. In BS EN 40101, 'user experience' is one of the lighter aspects of study, with minimum requirements for undertaking a user experience survey supported by a survey template. We have shown how the two approaches (Quality of Life Framework and BS EN 40101) correspond/differ in the mapping diagram shown left. The topics covered in BS EN 40101 are useful to ensure a minimum expectation for standardisation of outcomes from POE/BPEs. However we felt did these topics did not go far enough in interrogating the full spectrum of quality of life and for how mass timber specifically influences these. A bespoke survey was developed, that sought to bridge the two approaches.

Additionally, we drew from a wider literature review of methodologies, standards and research papers relating to building design, performance and wellbeing assessments. This informed the survey design and engagement methods. For full detail on the survey template and approach, please refer to the MMT POE Report.

An alternative approach could have been to adopt the BUS methodology. However, this method is more extensive than the remit of what this project sought to evaluate, and the costs of commissioning this method are prohibitive to widespread adoption and upscaling, as it is a licensed method. Our hope is that with our MMT survey being available free and on open source basis, others can start to replicate and build a basis of understanding for what good looks like for quality of life in timber buildings, as well as in following the standard questions in BS EN 40101. We can then in the future benchmark the case studies.

> **Occupant satisfaction**
>
> *'The degree to which occupants prefer or dislike different aspects of internal environmental quality. It can only be measured through surveys and interviews.'* [81]

Research challenges

The quality of life study component produced more likely challenges that we needed to anticipate and/or overcome. These included:

1. Bias and leading questions

There were some initial concerns from building managers/owners about the direction of questions and the publicity of potentially sensitive information. However, emphasis on the anonymous nature of the project and data received allowed for all neutral draft questions to be approved. Questions were reviewed by project teams and efforts were made to remove any biased language and to use clear and precise phrasing at all times as well as 5-7 Likert scales where appropriate. Involving comparison in questions can result in leading questions, though it was deemed necessary to emphasise the timber design influence for this study. When considering life or building response satisfaction, endogeneity, or confused variables, are a likely problem. For example, it's difficult to tell whether people who are already looking to actively achieve a happier, more relaxed life, are more likely to then proactively seek this through interaction with timber or natural design.

2. Survey design and length

Efforts were made to create a survey which was small enough to attract responses, but that also covered the themes of BS EN 40101 and wider influences. Due to the different typology of building, some questions were more relevant than others. This resulted in 'core questions' remaining the same but 'context questions' shifting to suit the audience and building type.

3. Benchmarking

Due to the relative lack of data regarding POEs for mass timber projects specifically, emphasis was on summarising the findings from the case studies and suggesting this as valuable benchmarking/comparison evidence for the sector in future.

4. Communication with and access to the buildings / stakeholders

Logistics, communication and coordinating engagement visits proved challenging, limiting the survey response, for example particularly at Harris Academy, where safeguarding concerns and capacity amongst staff were barriers to engagement. Incentives were discussed initially but unknown potential respondent numbers made budgeting for this difficult. This is an important factor to consider for future studies, especially in public spaces where a prize draw or something similar could be an appropriate option.

A key consideration in undertaking this research component was around the practicalities of undertaking in-person research work and gaining access to the buildings in the most basic sense.

In buildings that are used to hosting visitors, such as 6 Orsman Road or Cambridge Mosque, access to the building is readily made through a swift and well-defined process. The designer-researcher may reach out to an openly available contact, dedicated to hosting visitors, comply with their safeguarding and safety instruction, and proceed with visits to interview occupants, share questionnaires, install sensors and access their data. Buildings such as Harris Academy will have necessarily stringent requirements for access centred on the safeguarding of students, making in-depth POE studies difficult to establish or maintain. Abbey Wood station may see thousands of visitors every day, but the management of the building is divided between multiple stakeholders, so permissions can be challenging to establish. In a private residence, like Rye Apartments, designer-researchers must negotiate the routines of residents and the changing of residents altogether, recognising that the average UK renter stays in a property for 19 months. Within the buildings themselves, additional changes have resulted in the relocation, and thus decommissioning or even loss of sensors mid-review. From the outset each building incorporates spaces that are either public or private facing, e.g. the common spaces of 6 Orsman Road vs. private rented rooms and floors, making access variable. Other buildings may see changes in occupant throughout the day, which again compromise ability to access spaces on arranged visits, such as the prayer hall of Cambridge Mosque or the any number of school classrooms at Harris Academy.

5. Reflecting whole life carbon analysis

Due to access and scope limitations the initial desire to have two main surveys, one for 'Users' (those occupying / living / working in the building or development) and one for 'Stakeholders' (views of contractors, builders, building managers and neighbours etc.) proved unviable. Efforts should be made in future to capture and reflect the whole-life process through widening the scope of POEs.

6. Findings and analysis

Ensuring the sample size is sufficient for appropriate representation can be tricky in public buildings and where visiting numbers are more fluid. Where numbers are more consistent, a 10% response level is usually a sufficient minimum. The total estimated occupant number at Orsman Rd was 856, however, due to the likelihood of lower average daily numbers we can assume that the 72 surveys achieved this minimum reach. Analysing the results through each theme of the Quality of Life Framework, despite and due to its holistic nature, is challenging when confined to the parameters of the building itself and materials used. The benefits of timber design exposure are evident and prioritisation of those benefits must come down to building purpose and use.

To be explored further

Our quality of life study has focused on the operation/in-use stage of the building life cycle. However, we have anecdotal knowledge that building in timber offers an improved quality of life to the workers and manufacturers working with the material in construction. There are also known reductions in construction traffic when working with DfMA approaches that timber systems lend toward, as well as the potential noise reductions through working with less intensive construction processes on site that could also enhance the quality of life of communities in the wider context around mass timber construction sites. We would argue therefore that when mass timber buildings are being constructed, there is opportunity to gather evidence on this and there is room for further research to appraise the quality of life implications before buildings are occupied. Perhaps too as mass timber buildings reach their end-of-life there is potential to capture evidence on the deconstruction teams' quality of life.

It is important to note that construction workers are at four times higher risk of suicides than the national average and there is an established mental health crisis in the sector, owing to the physical strain of the work, high pressure with deadlines and the insecurity of the work. There is considerable room therefore to improve quality of life for these workers, and if there is any potential for timber systems to support this then this should be considered as a factor, arguably as part of CDM analysis of potential construction systems.

Implementation of the method

Overall, 110 surveys were conducted across the five sites, asking participants what they feel about the building they spend time in. Due to unforeseen engagement, outreach and communication challenges across the different sites, some sites received many more responses in comparison to others. And due to the limited numbers, apart from 6 Orsman Road, the POE data received should not be seen as a truly accurate representation of the views of all building occupants. Alongside subjective POE surveys, monitoring of indoor air quality (Airthings) was also performed in conjunction in order to compare qualitative data with environmental records. Despite some difficulties in recording seasonal averages, the air quality data does correlate to some specific remarks made by survey respondents. This is especially true when considering room temperature and comfort. This will be explored further later in the report.

Outreach activities included sharing flyers and facilitating pop-ups at the sites, as well as sharing digital social media assets. The survey itself was primarily shared as a QR code or URL link via the SmartSurvey platform. During pop-ups, physical surveys and recordings were also used for those who could not access the internet or preferred verbal communication.

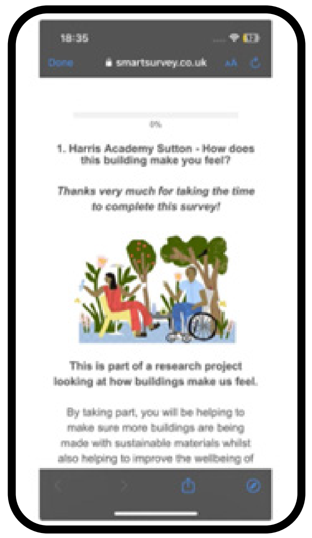


Figure 38. A snapshot of the online engagement tool (QoLF)

Figure 39. Photographs from in-person engagement activities (Photos QoLF)

Internal environment quality

Studying this aspect of the BS EN 40101 was to support the quality of life's user experience-oriented research. We see a benefit of recording both impressions of internal environment quality. The qualitative accounts of people living and working and using the buildings, underpinned with hard data to show if they were providing 'healthy' spaces against a series of standard data points and benchmarks. We knew that it would not be possible to extricate the role of 'mass timber' per se in the internal environment performance, because of course buildings' fabric performance arises out of far more than their structural systems.

Our main hypothesis was that we would see that the five case studies sit generally in line with best practice recommendations. This would demonstrate that mass timber buildings can provide a healthy environment, as a foundation to support wider quality of life aspects generated by the architectural and mass timber design.

Following a review of devices available to market at the time of applying for our grant, we decided to use Airthings Waveplus devices.[82] These devices were familiar to dRMM as these have been in place on a project (Maggie's Oldham) and in our own studio for a number of years. They are relatively affordable (<£200 each) and so would be replicable and realistic for others to adopt. We also know that other architecture practices have been using them on their own in-house POEs (e.g. Haworth Tompkins[83]) and so there would be some level of cross-comparison available quite readily.

BS EN 40101's sampling method suggests a threshold of 10% of homes to be covered in monitoring placement. As our study assessed buildings beyond the residential typology, we tried to be as representative as possible with the monitor placement in each building to cover a range of spaces in location and function in the buildings.

Internal environment quality

We take this to be a broad term. It includes the measurable performance of a building against a range of conditions factors, combined with the user experience as derived from surveys and interviews.[84] This multi-faceted evaluation gives an overall impression of how the building's interior provides for people. Internal environment quality affects people's health and quality of life very directly.

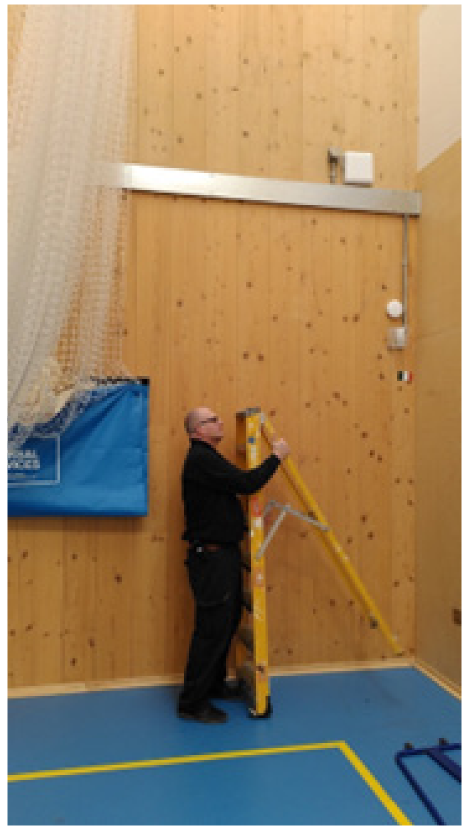
Internal condition monitoring scope

This table appraises the different aspects that the monitoring devices we used measured [88] and which of these we have analysed findings from in our case study BPEs.

Monitoring category	What does this tell us?	BS EN 40101	In MMT
Temperature	Thermal comfort is influenced by many factors beyond temperature alone (e.g. occupant clothing, air velocity, individual metabolic rates and personal preferences.[85] However, temperature is a significant contributing factor that is easy to measure. Temperature can also affect the 'growth and spread of microorganisms, such as mould and bacteria'[86] and can tell us about how efficient energy consumption for heating/cooling is.	Y	Y
Relative humidity	Humidity levels are linked to temperature, with high humidity potentially contributing to mould and bacteria, and low humidity contributing to dry skin and respiratory problem exacerbation.	Y	Y
CO_2	Carbon dioxide builds up when humans exhalation rates are not met with an exchange of fresh air supply. This can be hterefore a good proxy for understanding how well ventilation systems are performing. Excess carbon dioxide can also cause problems such as headaches, dizziness, fatigue.	Y	Y
VOCs	Volatile organic compounds is a group of chemicals that are airborne. These can come from human activites in the building - e.g. cleaning products, cooking - or from the fabric of the building itself - e.g. the materials the building is made of might off-gas. Mass timber is often a laminated/glued material. This presents the potential for VOCs to be generated by mass timber directly, which we were interested to explore. Different VOCs have different health implications, ranging in severity.	N	Y
Radon	Radon is a radioactive gas, which is naturally present in soil/rocks and can make its way into buildings 'through cracks in foundations.'[87] It is thought that 'long term exposure to high levels of radon can increase the risk of cancer', however there are a lot of myths about the actual risks radon presents in usual circumstances.	N	N
Air pressure	Air pressure is generally affected by external conditions outside the building. It can affect the circulation of air in the building, but the effect of the mass timber structure on air pressure if at all would be very challenging to determine.	N	N

Monitoring device placement requirements

Criteria	BS EN 40101 requirement
Distance from any radiator	More than 2m horizontally
Distance from any window	More than 2m horizontally
Distance from floor	Between 0.8m and 2m vertically and no closer to the ceiling than 0.8m
Distance from any ventilation terminal	More than 2m horizontally or vertically
Distance from any heat generating appliance (>100W)	More than 1m horizontally or vertically
Distance from inside surface of any external wall	More than 100mm horizontally
Distance from any internal or party walls	Can be mounted on any internal or party wall as long as the sensor is measuring air (and not surface) conditions
Direct solar gain	Sensors located to avoid any direct solar gain wherever possible
Sensor accuracy	Maximum of +/- 0.5C temperature
	Maximum of +/- 3% relative humidity
	Maximum of +/- 50 ppm (carbon dioxide)
	Calibration in accordance with manufacturer's recommended intervals and requirements



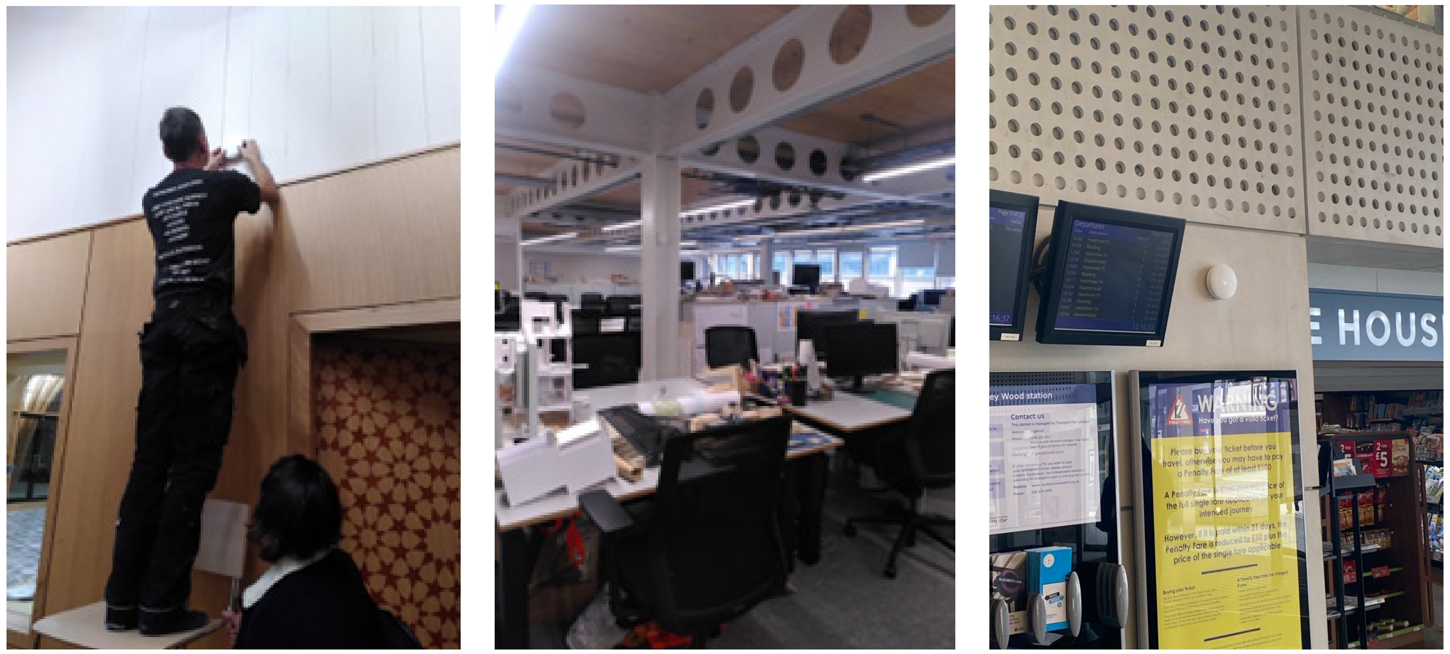


Figure 40. Photos of monitoring devices being installed/in situ in case study buildings (Photos dRMM)

Challenges

The internal condition monitoring area of the MMT research project was where most of our challenges in implementation arose. Alignment with BS EN 40101 was something we retroactively sought to achieve after having initiated the research project. We extended the research programme significantly to accommodate a fuller internal condition monitoring process, however we still found additional time was needed for stakeholder engagement in implementing installation of the devices.

Stakeholders were generally nervous of this study aspect - what would we find? What would the data show? Would people mind/notice these devices and be unhappy with the monitoring being taken while they are in the building? Would the devices damage the building somehow in how they were affixed? These were all questions we had and needed to overcome through sharing information about monitoring process and developing complementary communication materials. This suggests a widespread unfamiliarity with this sort of building analysis in industry, and a lack of awareness of the role buildings play in supporting quality of life and health in particular.

While we sought to observe the BS EN 40101 guidance for **placement of devices spatially**, in practice the positioning was constrained by aesthetics. Building owners and occupiers expressed a desire of not wanting to clutter visually the spaces. We generally sought to place them near to other monitors/alarms/information panels as possible. An additional consideration was avoiding being knocked/disturbed during the monitoring period. In reality the architectural layout of spaces sometimes resulted in sub-optimal device placements against the recommendations in BS EN 40101.

The **recording intervals and measurement tolerance** of the devices was not wholly compliant with BS EN 40101, but we felt was near enough to be valid. The market availability of devices that are as sensitive as required would have been prohibitively expensive within the project budget given the number of monitors we were placing in buildings concurrently. This would not likely be replicable easily at a larger scale for others to undertake too. It was also important for us to use a consistent device throughout the monitoring to limit inconsistencies in data collation between case studies/spaces. A review of data collected showed relative consistency and a post-monitoring calibration check showed good alignment between devices.

The monitoring period being one year long at least meant that each building had a **significant volume of data generated.** To generate useful, concise findings across five buildings with such varied use patterns was a challenge of data representation for replicability.

The most frustrating challenge was in the **hardware/software reliability**. We found that the interface between devices and syncing their data via Bluetooth a not very reliable one. Periods of data were lost at several points across the range of buildings during the monitoring process. With internal condition monitoring this means either overcoming patchy data, or leaving devices in situ for longer to make up for the time lost. Our best outcomes with using these devices were in the instance that we were able to connect directly into a Wi-Fi hub, with a live feed uploaded continuously. The practicalities of visiting the buildings frequently enough to sync the data and minimise losses was underappreciated by the research team in the early days, with optimism of following the manufacturer's expected data storage time and battery life. We have fed back our experiences to Airthings. We found there were problems with syncing in part also, we suspect, due to the mass timber structures. Bluetooth and Wi-Fi were both seemingly affected by the mass timber structures in all buildings. We suspect there is an interplay between the 2.4Ghz frequency microwaves with the dense organic material in the timber structure which may have contributed to our challenges in this systems' application. More appraisal of devices is recommended before embarking on similar evaluations - a little more time (and money) upfront is worth it to maximise the outcomes of data monitoring.

Our main learning is that **inserting sensors after a building's construction while not ideal**, regardless of what device is used, but **can be optimised through careful selection of device and through any monitoring strategy.** Ideally, buildings can be kitted out with monitors prior to occupation. If monitoring for internal conditions could be also combined with a moisture monitoring system, like the one discussed on page 24, this would be even smarter as a holistic method. Where studies are being undertaken like this one with post-construction installation of devices for BPE, we recommend learning from our experiences to inform your approach to limit the same issues affecting you. We would hope with more people undertaking this research type that a wider range of affordable continually connected devices will become available.

There are still data protection issues to overcome however, even in pre-installed permanent devices. In particular, sensitivities about how this data would be used/stored and how to get occupant sign-off in early stages of building occupation/with tenant turnover. Until there is more widespread BPE into internal environment quality, we expect that others will face similar challenges as we have encountered in supporting stakeholders to appreciate the need.

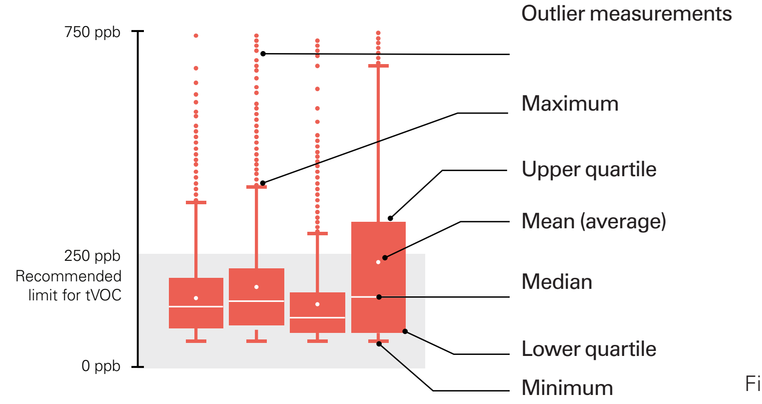


Figure 41. How to read box plots

Data representation

We have included in our Findings section a series of simple figures and representations of that data that we feel best explain the range of information we have acquired in the process of undertaking the internal condition monitoring aspect.

Degrees Celsius for temperature is a unit that we all use in everyday parlance and have a physical awareness of the implications for ourselves (even if wet bulb versus dry bulb temperatures are less well understood as a concept). However, for metrics such as VOCs, CO_2 and Humidity we did not feel that there is sufficient understanding of what these units mean and what 'good' looks like. For instance, we all collectively have a grasp for what degrees Celsius feels like as a scale, and can relate this to our own thermal comfort preferences to some extent. But what does it mean when CO_2 levels in a space reach 1200ppm?

To simplify communication of all these metrics we have represented their results in a scale of recommended ranges. We have also normalised the findings.

We have chosen to represent data using box and whisker plots, as these are effective ways to represent lots of complexity in quite a simple visual output. They show the distribution of data in its entirety from minimum to maximum data points, as well as giving the average upper quartile and lower quartile. The box holds 50% of all data.

Benchmarking

We have referred to a wide range of literature sources to inform development of recommended ranges/thresholds for each of the monitored internal environment aspects. See table below for full information. More work is needed in industry to develop replicable benchmarks for these characteristics.

MMT recommended ranges for internal environment - overview

Monitoring category	Recommended range	References informing this	Rationale	Limitations
Temperature/ comfort	Within +/- 2.5 °C from adaptive comfort temperature	90% acceptability band within the adaptive comfort model (BS EN 7730/ASHRAE55)[89, 90]. Using a simple arithmetic running average for 30-day outdoor temperature.	Adaptive comfort model incorporates human factors in its definition, particularly in relation to activity level, external temperatures and associated clothing levels. It offers a more nuanced perspective of comfort and range of individual preferences than hard-coded temperature ranges.	Model has been specifically developed for naturally ventilated and non-conditioned spaces. It assumes subjects are adults and are at low physical activity level (such as at home or office). Deviations from these assumptions must be considered when assessing results.
Relative humidity	Between 35% and 60%	Several standards and best practice recommendations variably refer to 30/40% to 60/70% range, namely, CIBSE Guide A, ASHRAE62, Passivhaus, etc. [91, 92, 93]	Recommended range aims to balance limiting growth of mould, virus and mites, while offering comfort to occupants and dispensing strict operational control or mechanical devices within the UK climate.	Range shouldn't be seen as having hard boundaries, since temporary excursions outside of the recommended range should still be perfectly fine.
CO_2	Less than 1000 ppm	There are no strict regulations regarding CO_2 levels, but multiple standards advise keeping CO_2 levels to below 900 to 1500 ppm (e.g., EN13779, ASHRAE 62.1, and many European national regulations). [94]	While CO_2 is not considered a pollutant itself, it is generally used as a proxy for ventilation effectiveness. Thus, a conservative 1000 ppm can be used as a reference to understand if indoor air ventilation rates are adequate for that space's occupation and activities.	Short-term exposure to CO_2 levels much higher than 1000 ppm are generally recognised as being safe, despite having been shown to cause negative impacts to productivity and comfort. Thus, longer-term average exposure is more relevant.
tVOCs	Less than 250 ppb	Sensor-specific calibrated Airthings settings (recommendations from sensor manufacturer). Many international standards recommend a maximum of 500 µg/m³ (LEED, WELL, etc.) [95, 96] which cannot be easily converted to ppb without knowing the composition of volatile compounds.	Given the complex family of substances that fall under the "VOC" definition, and the sensor-specific sensitivity curves, it is best to rely on manufacturer specifications, rather than general standards that may or may not align well with the sensor's outputs.	Comparison between different brands of VOC sensors is troublesome and that makes it very hard to take solid conclusions solely based on these results. Furthermore, many benign substances are known to be detected by VOC sensors, breaking the strict link between VOC measurements and potential impacts to health. These should be understood as a general first step in identifying potential issues which should then be followed up with compound-specific measurement for better clarity.

Research ethics

A challenge with industry-led research is that there is no code of conduct for research integrity, ethics and safeguarding as standard in the architecture industry (beyond the codes of conducts as set out by RIBA and ARB for professional services). This is however a fundamentally critical aspect of conducting research, especially when involving a wider community.

We sought guidance from the practice research expert Flora Samuel at an early stage to ensure the research study as a process was in line with best practice. We also undertook research to inform project specific policies and processes.

For those unfamiliar with research ethics, we would recommend reading the 'Concordat to support research integrity'.[97] In line with the Concordat, we felt it was paramount that all aspects of this study should be conducted with honesty, rigour, transparent and open communication, care and respect and accountability. By partnering with Edinburgh Napier University, we had input and oversight throughout on best practices for research integrity safeguarding. Edinburgh Napier University guidance including their 'Code of Practice on Research Integrity' and their 'Research Safeguarding Framework' were useful for the wider research team to be aware of in embarking on this study.

Stakeholder engagement & consents

To facilitate the research project, we have needed to engage with a range of wider individual stakeholders for each of the case study buildings, including:

- architects participating in the study
- building owner/managers we were seeking approvals from for participation in the study
- building occupants/users detailing the study aims in simplified terms

Some key literature was generated including a summary information booklet tailored to various parties. We also developed consent forms derived from the templates contained in BS EN 40101. We sought signed consent from participants to outline that they understood the research study aims and how and what of their data would be used. More detail will be given in the next section on the role of consent in a wider ethics and safeguarding context.

Ethics and safeguarding

Safeguarding was a particularly integral part of this study, given the nature of the proposed in-person visits, interviews and surveys within the community. Each building had its own unique circumstances to consider.

We were required to develop a project-specific safeguarding policy to comply with Built by Nature's funding requirements.

As a summary, the core principles for undertaking this research were as follows:

- Protecting the rights, interests and safety of participants, research project collaborators and team members
- Comply with all relevant privacy legislation including data protection and duty of confidentiality
- Have all necessary approval and consent in place during research
- Meet the appropriate regulatory and/or ethical requirements and follow best practice guidance
- Shared responsibility for upholding best practice for research integrity and ethics

The terms 'ethics' and 'safeguarding' are not referenced in BS EN 40101. There is however frequent reference to consent – in particular reference is made to 'necessary consents', 'explicit consent' and 'early consent'. We would encourage moving beyond a concept of 'consent' towards 'informed consent', such as is required in medical practice, to be transferred to BPE work as a way of approaching the ethical consideration of working with a wider public, and possibly even setting a stretch goal 'enthusiastic informed consent' for all participants.

It is our finding that participants are supportive of BPE work where they understand the bigger picture and wider benefits, even if those benefits will not be directly for themselves but for a wider public good (improving the design of buildings, learning and progress for those designing buildings, environmental improvements arising from construction sector). Participants in this study had concerns around use of data, how invasive in-building monitoring may be, potential for damage to the building fabric through installation of devices and more. These concerns were all explored and we sought to overcome misconceptions around the sort of work we were undertaking, particularly for the in-building monitoring.

To secure enthusiastic consent, suitable time is needed upfront to explain the study goals and objectives and how its findings might be of interest or use to the stakeholders being approached for engagement. This is why we suggest allowing at least 3-4 months up front for this phase of work, so as not to rush the process.

Of the buildings we studied, there were a range of likely communities we were going to be exposing the research team to and interacting with. This meant there was a two-way importance to consider safeguarding – both of the research team directly and of those we interacted with through building visits and interviews/surveying methods. The Quality of Life Foundation led on safeguarding best practices for this in-person safeguarding best practice.

One key consideration on this research project was the likelihood/inevitability of working with "vulnerable" persons. This most directly was anticipated to include children in the education building, but also we expected the potential of encountering vulnerable persons (adult or child) in the range of buildings we were visiting. Risk assessments were undertaken for each of the case study buildings for the research activities.

One core protection method was to ensure all research team members participating directly in activities where they may encounter children and vulnerable persons was to be DBS checked. The Quality of Life Foundation's Code of Ethics and project-specific safeguarding approach was approved by Built by Nature ahead of any in-community research activities.

We would recommend others undertaking in-community research activities to be mindful of safeguarding best practice and consider appropriate measures for their work to be undertaken safely and respectfully.

GDPR

GDPR is of course an important consideration when handling data, and BS EN 40101 sets out guidance on this as follows:

'*Data gathered in the course of a BPE project is likely to include personal data and building data that might pose a commercial, security or privacy risk. BPE projects place the evaluator in the role of data controller and/or data processor, as defined under GDPR and thus the responsibilities under these regulations apply when collecting, processing and retaining data provided by individuals" (...) Good practice in BPE studies includes ensuring appropriate consent is obtained at the planning stage to access necessary data, including surveying occupants and building users as well as accessing building data.*'[98]

Again we see the recurrence of 'appropriate consent'. One interesting aspect of this is 'commercial risk', which was a core concern for some of our project participants – what would happen if the research study and findings identified aspects of the building made people unhappier, uncomfortable and therefore less willing to pay to live/work/study there?

Key takeaways

We see industry-led research to be important, particularly in building a large dataset of evidence for mass timber's performance in quality of life and whole life carbon. It is important for anyone conducting this research to develop suitable processes and procedures relevant for this type of BPE evaluation and the project-specific circumstances to be delivered safely and respectfully. Ensure that stakeholders involved have given 'informed consent' and ideally 'enthusiastic informed consent' to participating in research.

There are well-established methods available, including proformas within BS EN 40101. Spending time developing these mechanisms upfront reduces potential risks involved in conducting this work, while helping to ensure research is of a good quality and has integrity. Observe GDPR rules in handling data.

Case studies

3

ABBEY WOOD STATION
FEREDAY POLLARD ARCHITECTS

CAMBRIDGE CENTRAL MOSQUE
MARKS BARFIELD ARCHITECTS

6 ORSMAN ROAD
WAUGH THISTLETON ARCHITECTS

PECKHAM RYE APARTMENTS
TIKARI WORKS

SUTTON HARRIS ACADEMY
ARCHITYPE

IN THE FUTURE...
MORE CASE STUDIES ACROSS A RANGE OF TYPOLOGIES & LOCATIONS

Figure 42. Case studies overview
(Photos clockwise from top left: Richard Lewisohn, Morley von Sternberg, Jack Hobhouse, Jack Hobhouse, Ed Reeve)

Overview

This section of the report presents the key findings from applying the Measuring Mass Timber methodology across the five case study buildings. We have reported findings in a consistent and relatively concise format that can be replicated on a wider range of case studies in the future.

To recap, the five case study projects are as follows:

- Abbey Wood Station, Fereday Pollard Architects
- Cambridge Central Mosque, Marks Barfield Architects
- 6 Orsman Road, Waugh Thistleton Architects
- Peckham Rye Apartments, Tikari Works
- Sutton Harris Academy, Architype

The report is formatted to be consistent graphically across the five case studies. We hope that this increases the ability in the future to add many more case studies to the dataset with the methodology applied, to provide a bigger snapshot of the role of mass timber in contributing to decarbonisation and quality of life.

The case studies are structured as follows:

Project information

This section captures fundamental project information, describing how the building is used and how mass timber systems have been implemented.

Whole life carbon

Whole life carbon impacts are appraised in aggregate and broken down into embodied carbon, operational carbon, sequestered carbon. A mixture of tables and charts is used. The buildings are benchmarked against relevant industry limits/targets (where available).

Quality of life

Starting with the internal condition monitoring, we share high level summaries of the main findings across the monitoring periods and the practical aspects of undertaking this part of the study for each building. These are presented in benchmarked box plot charts. We then explore the user experience study component, using a combination of infographic and chart-based representations to convey our findings.

Discussion

We zoom back out to a wider view here, bringing the two main study strands into conversation with one another. We also draw upon wider reading and reflect upon the implications for industry based upon we have learnt from the findings. We also reflect on the practical challenges or successes of implementing the methodology for each typology building.

Figure 43. Station as seen from the East frontage to Harrow Manorway (Photo Richard Lewisohn)

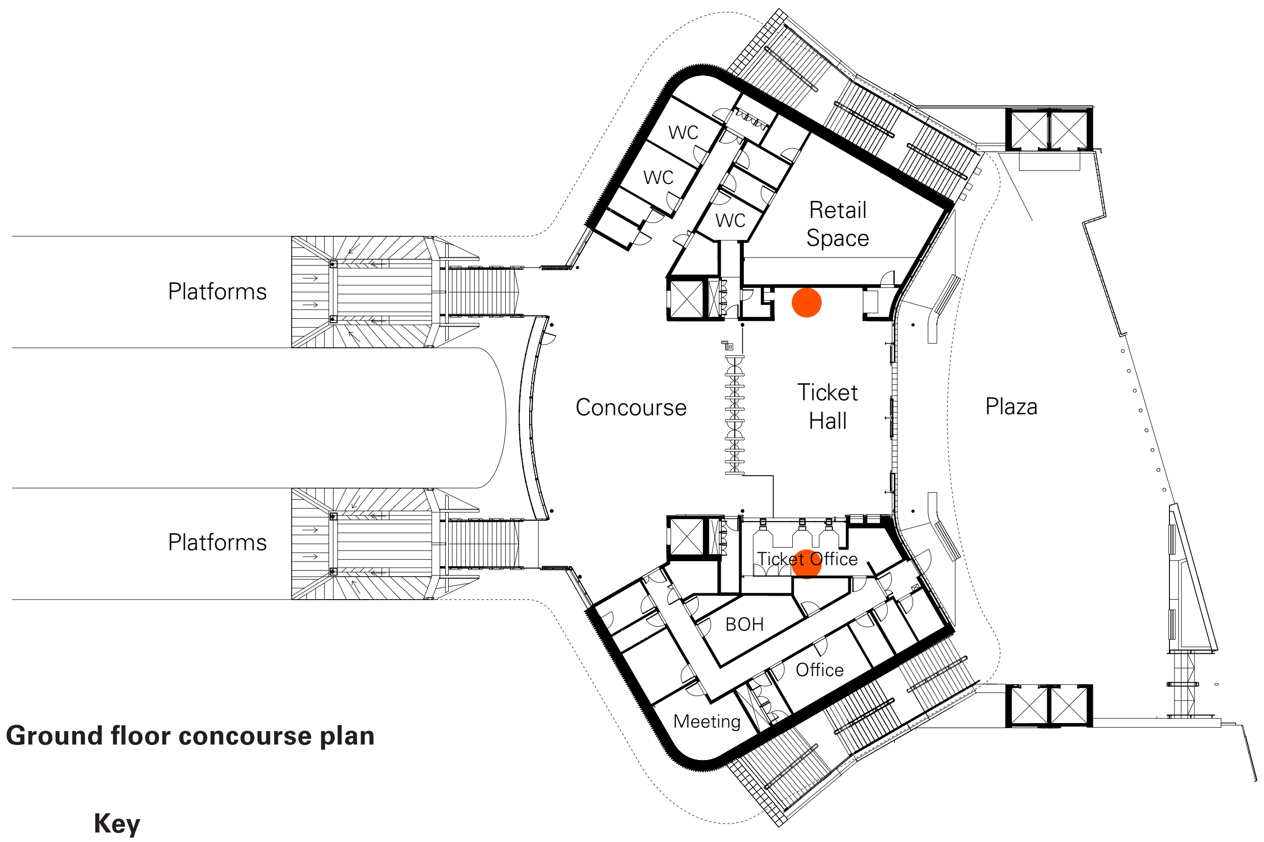
Figure 44. The curved larch glulam structure spans over the main concourse and ticket hall (Photo Richard Lewisohn)

Abbey Wood Station

Project information	
Building type	Transport infrastructure - a railway station
Location	London
Date completed	Full completion 2020
Gross internal area	882 m²
Mass timber application	Glulam beams with CLT deck roof
Architect	Fereday Pollard Architects Ltd
Structural engineer	TGP
Timber contractor	Wiehag GmbH
Main contractor	Balfour Beatty
Project management	WSP
Client	Network Rail/ TfL Crossrail

Abbey Wood station is a **new train station facility** on the South East Spur of the Elizabeth Line, denoting the start and end of Crossrail's journey to and from central London whilst serving Southeastern and Thameslink rail services. A station has been in this location since 1849, with a replacement in 1987, superseded by this iteration. The new station provides enhanced railway formation, two new bridges and four new platforms. The building now provides access on three sides of the building, and incorporates significant areas of new public realm. Altogether, these design moves seek to provide a more accessible station supporting new infrastructure services.

The distinctive **curved roof is made of glulam beams supporting a CLT deck**. Formed over two main levels, the station is encompassed by an organic stingray-like form with a new plaza leading into the main ticket hall and concourse leading down to symmetrical platforms, with wings containing back-of-house areas and front-of-house retail and ticket office spaces. The mass timber structure of the roof is integral, spanning the entirety and extending externally to provide generous external cantilevered shelter beyond large **glazed facade areas**. Internally, the glulam provides a **large column free zone**, aiding free flow of pedestrian movement. The roof was constructed over a fully operational railway. **Prefabricated** roof sections were installed during very constrained timeslots of track closures.



Ground floor concourse plan

Key

● Position of internal condition monitors

SCALE: 1:500 — 0, 5, 10, 25, 50m

Whole life carbon

As an infrastructure building, Abbey Wood Station is designed on the basis of a 120 year design life. Following RICS guidance, this design life is the basis for our study. Infrastructure buildings must be resilient against vandalism, the huge numbers of passengers and for withstanding the wear and tear of a bustling city location. High levels of robustness mean the adoption of longer lasting, often higher-carbon products. Infrastructure buildings have important considerations for security, accessibility and safety.

It was challenging to determine a 'fair' spatial study boundary given the interconnectedness of the building with wider infrastructure. We determined the study boundary to include the facility located immediately under the main roof form, excluding the wider platform environment beyond the timber-covered stairs. Within this boundary is the concrete and steel structure and piles below the concourse, designed to withstand train derailment. The structure is also designed to support fire engine access onto the concourse above the railway.

A design challenge was to provide level interconnectivity for accessibility within the station's wider context, with limited headroom resulting in a thin concrete deck solution and subsequent higher carbon impact of the system than may otherwise have been adopted.

The mass timber structure of Abbey Wood station makes up just 0.07% of the building's carbon emissions from modules A1-A3. Concrete structural elements contribute most to carbon emissions at a product level, followed by metals found in the steel or aluminium structures and the robust finishes. However, even with mass timber representing a relatively small portion of carbon impacts, the roof still sequesters an impressive 842 tonnes CO_2e.

Life cycle assessment results:

Life cycle stage	tCO_2e	$kgCO_2e/m^2$
Product stage (A1-A3)	1,523	1,727
Construction process (A4-5)	220	250
Upfront embodied carbon* (A1-5)	**1,743**	**1,977**
Upfront biogenic carbon (A1-5)	**-315**	**-357**
Replacement (B4)	2,805	3,180
End-of-life (C1-4)	626	710
Embodied carbon (A-C excluding B6 & 7)	**4,332**	**4,911**
Energy use (B6) (decarbonised**)	654	742
Water use (B7)	8	9.3
Total WLC (A-C)	**4,994**	**5,662**
Benefits and loads beyond system boundary (D)	-1,066	-1,209

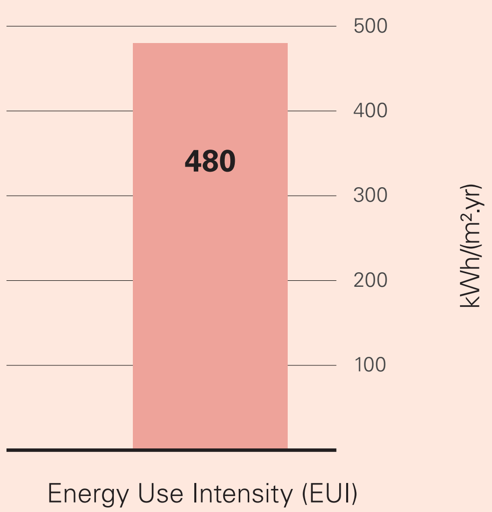
* upfront biogenic carbon is not incorporated in Upfront Embodied Carbon. Sequestered carbon is only accounted for (i.e. deducted) in Embodied Carbon across A-C modules in line with best practice.

** we have adopted a decarbonised grid scenario for the Energy Use prediction. Refer to Methodology for full explanation.

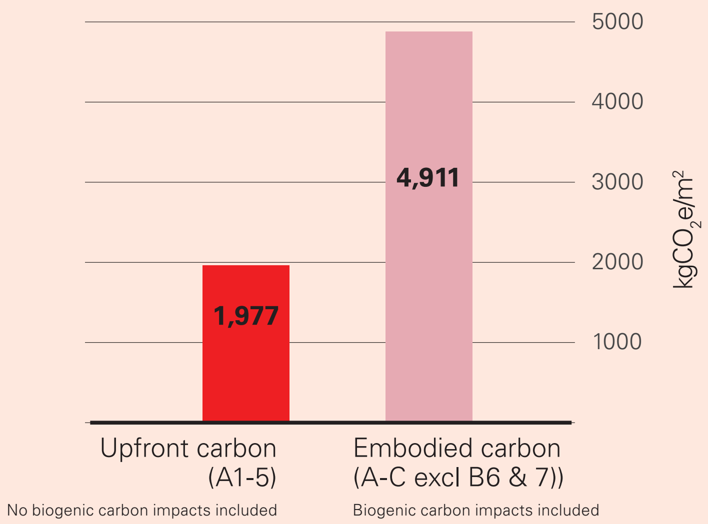
Benchmarking

This is the only one of the five case studies without benchmarks. Infrastructure buildings are not widely assessed for WLC as yet, or at least the results from these studies are not made available publicly.

Energy Use Intensity (EUI)

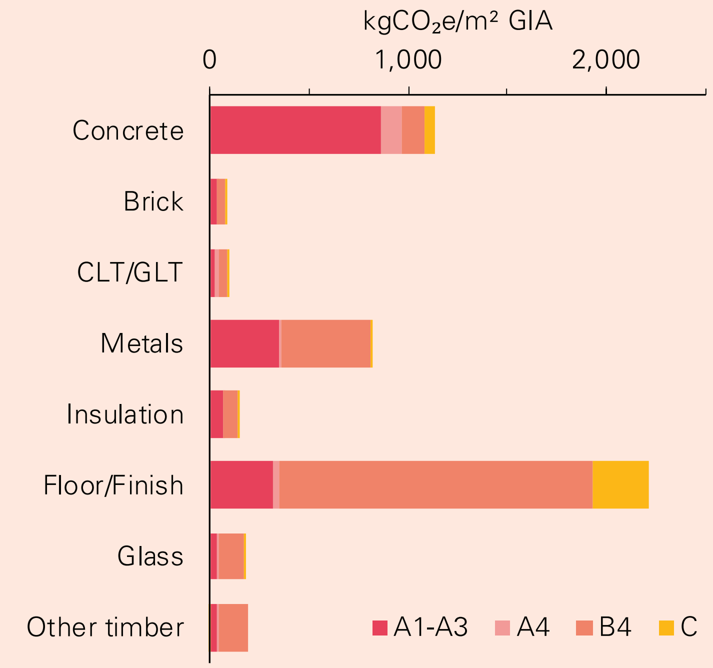


Embodied Carbon



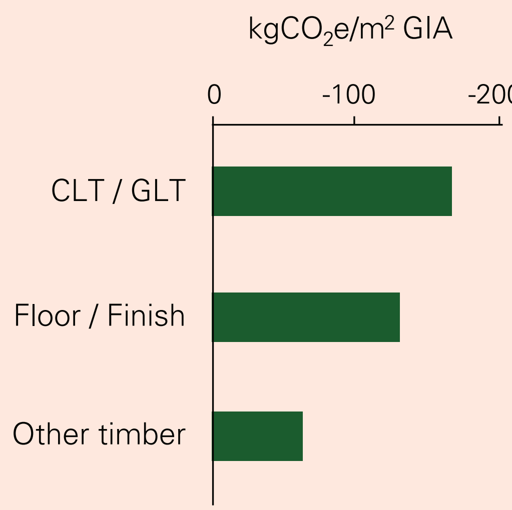
Embodied Carbon by material

The building's long design life means that shorter lived products have more replacement cycles than in a typical building's 60 year design life. This results in typically higher up-front carbon impact elements being reduced in impact across the whole life as compared to other shorter-life products. Finishes including flooring comprise the majority of whole life carbon emissions, with a significant replacements impact arising through the building's long design life owing to shorter predicted lifespans.



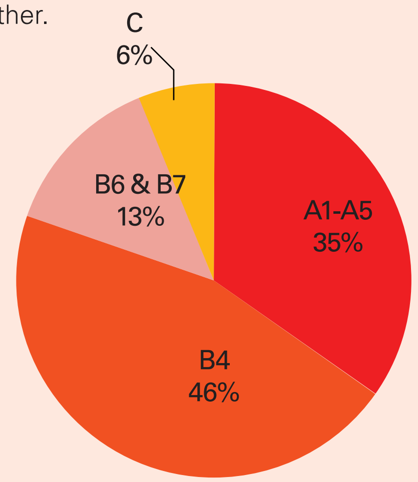
Upfront biogenic carbon by material

CLT and GLT are the main biogenic element of upfront carbon. Other timber in the facade, build-ups and finishes do contribute a fairly sizable proportion of the overall sequestration. Carbon is likely to remain stored in these mass timber elements for a long timeframe, given the unlikelihood of replacement of the station building.



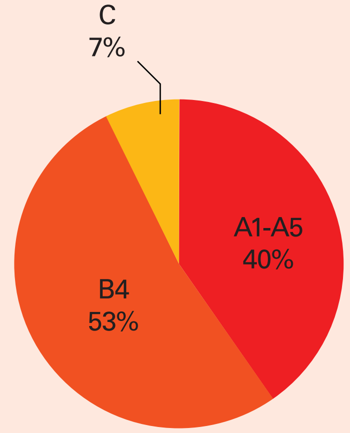
Whole life carbon (A-C)

Here the effects of sequestration are incorporated (i.e. the carbon stored in biobased products is deducted). NB: The carbon pie charts are shown relative in scale to one another.



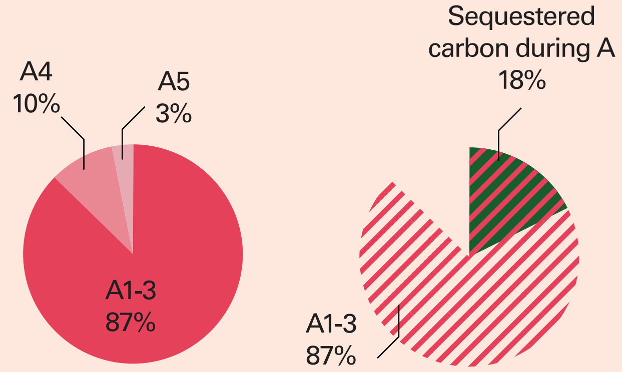
Embodied Carbon (A-C excl B6 & B7)

Here the effects of sequestration are incorporated. This is a typical scope used when benchmarking, with EUI typically benchmarked separately.



Upfront embodied carbon (A1-5)

When reporting upfront embodied carbon alone, the effects of sequestration cannot be incorporated. Shown below are the scale of sequestration impacts as part of A1-3 as a point of additional information.



Quality of life

Internal condition monitoring overview

The building is not fully-enclosed, with large facade openings. The internal environment is therefore only partially regulated by the building fabric - protecting people from strong winds, sun and precipitation. The building is recorded as tracking quite closely the external environment, with the concourse sensor closest to the outside recording very low temperatures and high levels of humidity. This semi-enclosed nature to the building makes analysis of the building's impact challenging.

We placed monitoring devices in the open concourse area and in the ticket office. Station visitors move through the building relatively quickly, without spending too long inside as they make their way down to the railway platforms below. They will be likely dressed for outdoor weather and unlikely to want to remove/add layers for a short visit to the building. The staff working in the building have some level of control over their individual comfort, as can be seen with increased temperatures recorded in the ticket office. They too will be likely dressed for working indoors and outdoors.

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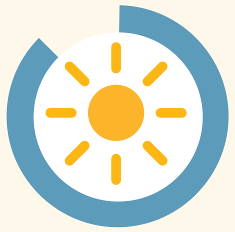


90% of building users were satisfied with levels of daylighting

75% of building users felt positive about the air quality

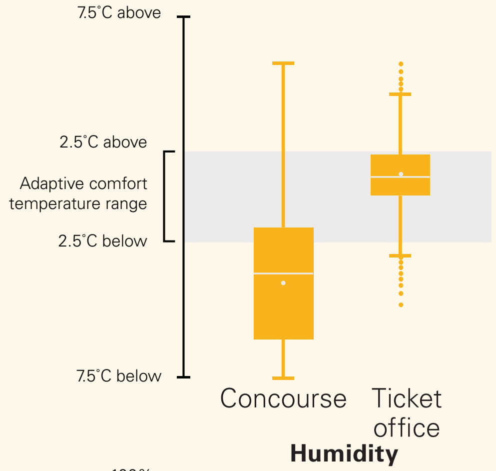
Internal condition monitor results

Category	Findings
Internal Temperature	The Concourse sensor's temperature readings align with the outdoor daily maximums, while the ticket hall sensor indicates comfort levels that are slightly elevated but still acceptable. About 23% of readings exceed the adaptive comfort range, which is tolerable due to the area's temporary use.
Relative humidity	Relative humidity trends are similarly acceptable.
Air Quality	The concourse device's CO_2 levels are typically below 500 ppm, aligning with external air quality. The ticket office has higher CO_2 levels but generally stays within excellent standards. Peaks averaging 700 ppm coincide with the station's busiest hours, from 6 am to 8 pm on weekdays. tVOC concentrations are elevated on both sensors, suggesting poor outdoor air quality, likely due to nearby traffic. This is supported by higher VOC levels being observed during peak commuting times (7-9 am and 4-6 pm).

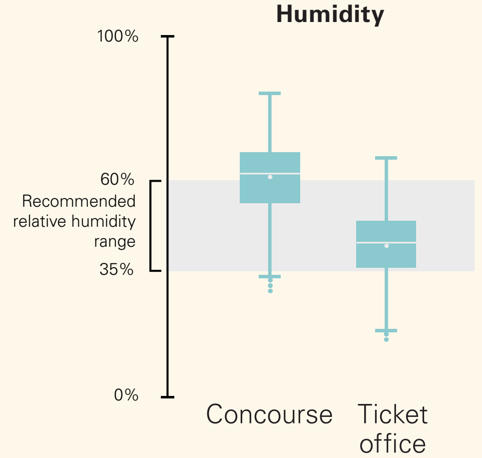
Internal condition benchmarking

See the Methodology chapter for more information on source data and interpreting box plot charts.

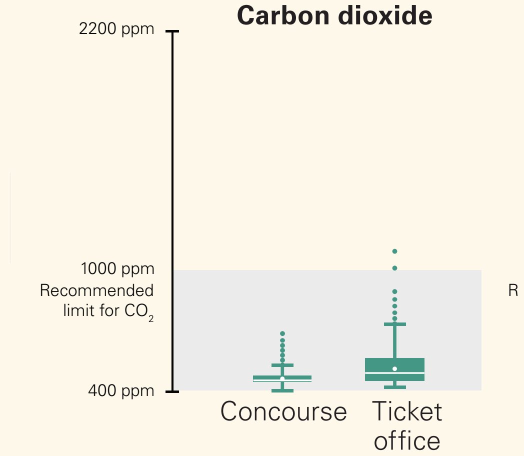
Temperature



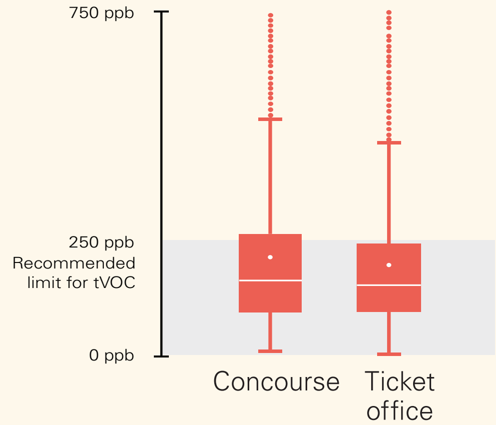
Humidity



Carbon dioxide



tVOCs



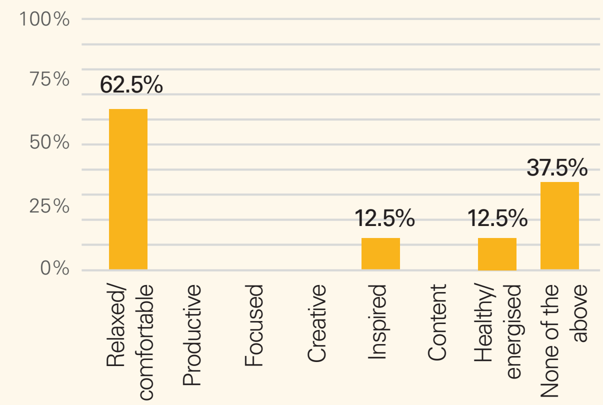
User experience overview

There were 11 respondents to the survey during our visit to the station, reflecting the challenge of capturing interest of people who are in transit. Of all design features, respondents felt most satisfied (87.5%) with the amount of daylight at the station. Regarding the mass timber specifically, 75% of visitors felt positive about the timber/wood features, the same proportion felt that the wooden features had a positive impact on their health and wellbeing, whilst 62.5% feel that the materials in the building remind them of the natural world.

60% of occupants were made to feel more relaxed and/or comfortable by timber features

60% felt the materials in the building reminded them of the natural world

Compared to other stations, the timber features of this building make me feel more...



What do you like about this building?

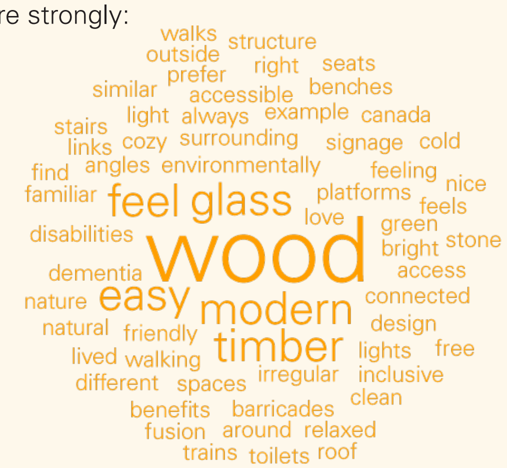
"Modern, easy to find your way around, light and accessible for those with disabilities"

"Not all right angles. Irregular. Fusion of glass and wood."

"buildings made from wood and stone always made me feel more relaxed."

"It's nice and cosy."

Of all responses to this question, wood and timber feature strongly:



User experience survey results

Category	Findings
Satisfaction	Occupants appreciate that the space and layout is 'not all right angles', and is 'nice and cosy', recognising that 'wood and stone made [them] feel more relaxed'.
Meeting user needs	Occupants felt the space was 'easy to find your way around, light and accessible for those with disabilities', 'clean with easy access to trains'.
Perceived impact on health and wellbeing	75% of occupants felt a positive impact on health and wellbeing. More than 60% were reminded of the natural world with an occupant noting: 'Wood feels familiar and environmentally friendly. Links with benefits you feel when in green spaces'.
Comfort and indoor air quality	75% felt positive about air quality, with the remainder neutral.
Sound	Mixed perceptions of sound; equal split of awareness of others inside the building.
Lighting	87.5% satisfied with the amount of daylight in the building. Several occupants appreciate the high levels of glazing to create an illuminated space.
Perceived control	One occupant felt the lights 'were too bright', many felt the space was easy to use.
Utility costs	-

Figure 45. Ticket hall. Monitoring devices were installed on opposing faces of the ticket hall environment. (Photo Wiehag)

Figure 46. Station arrival from the West beneath the mass timber roof structure (Photo Richard Lewisohn)

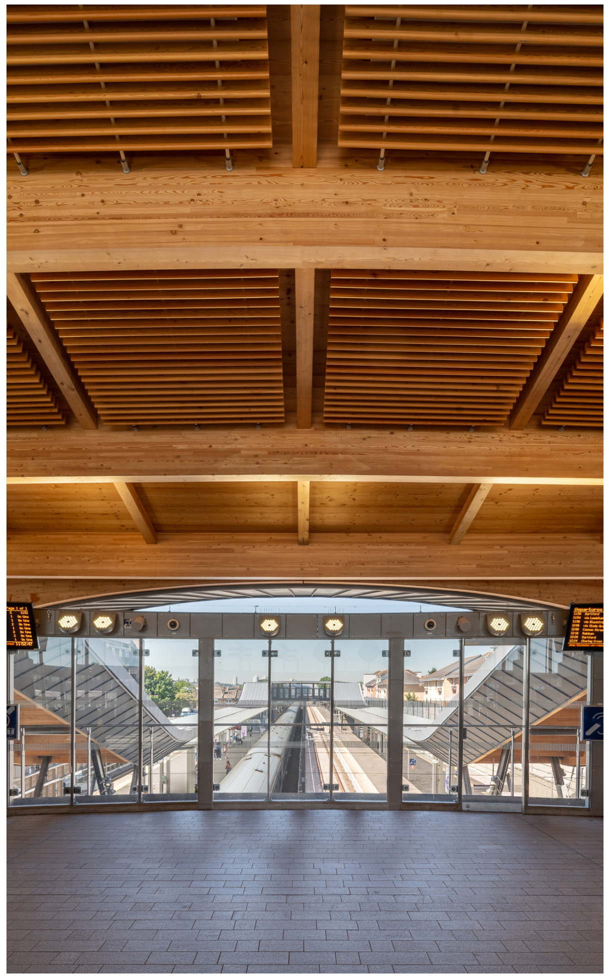


Figure 47. Traveller's view of the journey ahead (Photo Richard Lewisohn)

Discussion

Transport infrastructure buildings are not commonly designed in mass timber in the UK and are usually considered to be high carbon intensity buildings. There are very few examples of infrastructure building typology being studied (and findings shared) in carbon and quality of life terms, regardless of construction material type. There were some **challenges in undertaking the study** – with a range of stakeholder parties involved operating and running the infrastructure (who were very supportive of the study), with a complex and vast materials inventory, and with the very transient nature of the visiting public tricky to interrupt for surveying, as well as additional safeguarding considerations. Monitors were placed in the building, with their data readily retrieved given the public nature of the building.

At first glance this case study appears to be a building which emits very high levels of embodied carbon per square metre. But this is understood better when we remember that Abbey Wood station is subject to **onerous requirements in response to occupancy and security, with operational, constructability and engineering challenges**. Its architecture must be robust and enduring, accessible to support a considerable number of visiting members of the public. The building's **120-year life span** is longer than we would typically assume for other typologies (60 years). This means that while the impacts of upfront carbon emissions are shared out over a longer amount of time (halving their impact per year over a whole life effectively), the **impact of cumulative replacements** of building elements over a longer lifespan increases the impact, e.g. a 30-year life product would be replaced four times. This offers two impacts in relation to potential use of biobased materials – **sequestered carbon acts as a store in infrastructure buildings over longer time periods** (with some arguing that 100 years is permanent enough for a carbon store to become considered an 'offset'). And secondly, that where **biobased materials replace higher carbon materials in finishes and shorter lifespan products,** there is huge potential to reduce carbon and finite resource use over a whole life. No benchmarks currently are available to us for the typology, but **we hope that this study of Abbey Wood may support wider efforts towards future infrastructure benchmark availability**. We would expect this building to perform well in relation to such a benchmark.

One notable context point to this project's carbon story is that **there has been a replacement of station buildings in this location twice in last 150 years** – with a Victorian building constructed in 1849, a replacement station in 1987. This building was built primarily to accommodate a new train line - it is unlikely that this will happen again in this location for a long time. This context is important for consideration by commissioning bodies seeking the delivery of station infrastructure – to maximise carbon storage then infrastructure assets (indeed all assets) need to be part of wider urban planning strategy that limits replacements as far as possible.

Of course, the building represents a **small proportion of wider infrastructure works** undertaken to deliver the Elizabeth line. This perspective reminds us of the importance of thinking about other material and construction systems delivery in terms of carbon reductions for infrastructure projects. We have not reviewed the sustainability credentials of the wider line delivery as this is outside the scope of our study, but there was a sustainability strategy in place. Appraising intended reduction in carbon emissions arising from transport at a system scale is also out of scope –i.e. those choosing to travel by train over driving or other fossil-fuel based modes of transport. Without wider whole life data of new transport systems, we cannot fairly determine the carbon impact of one building in isolation.

This building is used by a huge number of passengers, with over **14 million journeys being taken from the station each year.** The quality of life potential at a population level of benefits arising from the building could be significant. Abbey Wood has been found to have impacted surveyed users as creating a 'cosy' and 'familiar' space, where **wood specifically contributes to 'feeling connected with nature' while being relaxed and comfortable.** We then can deduce that through known benefits of biophilic design and connection with nature as identified earlier in this report there are likely health and wellbeing benefits upon building users. The structural form also offers good quality daylight and connectivity to the outdoor world beyond.

Key takeaways

- Mass timber **can act as carbon storage** over long design-lifetimes in certain assets.
- In infrastructure assets, there is opportunity to **support improvements to quality of life for a very wide population** set, including an **enhanced connection with nature.**
- Considering quality of life (including accessibility) and carbon as a core part of the design process for transport infrastructure helps as part of ensuring that these buildings are well-loved and well-designed as part of **supporting shifts to lower carbon modes of travel**.

To be explored further

- It would be helpful to identify **'easy to transition to biobased materials' componentry in infrastructure design** to accelerate a transition more widely, appraising opportunity for easy wins/biggest impacts. Testing and application opportunities will arise via **creation of demand** for these products and solutions.
- Further exploration of asset types that offer **long-term carbon storage (and possibly even act as 'offsets').**
- A more **systems level carbon analysis** is needed to form **carbon limits for infrastructure** design.

Figure 48. Main entrance viewed through the Islamic Garden

Figure 49. View into prayer hall from the main entry point

Cambridge Central Mosque

Project Information

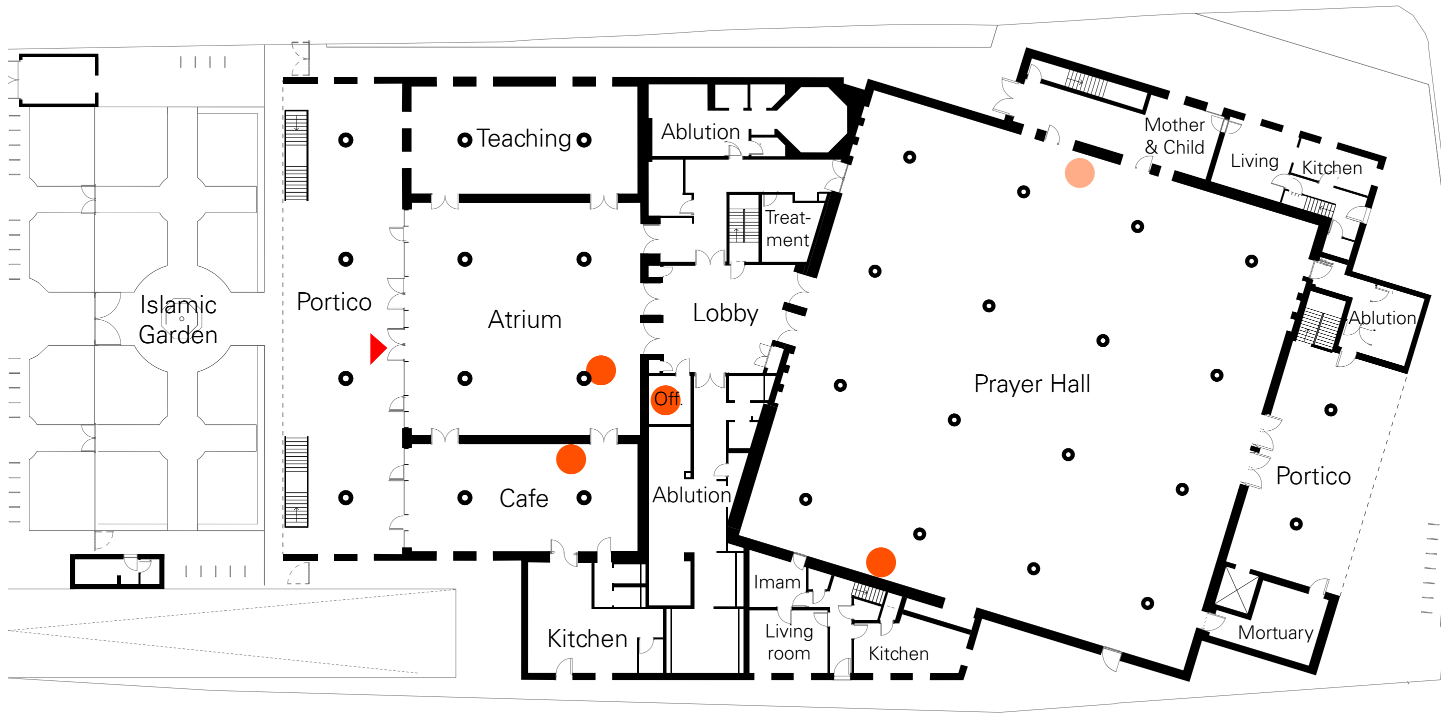
Building type	Civic / Public / Religious
Location	Cambridge
Date completed	2020
Gross internal area	4,900 m^2
Mass timber application	CLT external walls, intermediate floors, columns and glulam roof structure
Architect	Marks Barfield
Structural engineer	Price & Myers, Jacobs and Blumer Lehmann
M&E	Skelly and Couch
Fire consultant	Harris TPS

The Cambridge Central Mosque is the first dedicated new-build mosque in Cambridge. The building was originally designed to accommodate 1000 worshippers.

From the entrance on Mill Road, the visitor's journey starts from the Islamic garden, leading to a large atrium with adjacent café/community space, as well as a multi-use teaching and exhibition space. Worshippers make use of ablution wings before entering a large prayer hall with an upper-level balcony. Basement car parking holds up to 80 cars and 127 cycles.

Public spaces are unified by a network of 30 curved Glulam 'tree' columns. Mass timber is very expressive in its use in this case study, with these iconic 'trees' joining to form a lattice vault roof type structure. The roof form is reminiscent of those in the stone architecture of the proximate 16th century King's College Chapel. CLT is less visually evident though still substantial in the wall and floor structures. Timber is also used extensively in finishes.

Air-source heat pumps provide underfloor heating and cooling. Rooftop PVs generate power. Rainwater is harvested for flushing toilets and garden irrigation.



Ground floor plan

Key

- Position of internal condition monitors
- Internal condition monitor missing during study

SCALE: 1:500 — 0, 5, 10, 25, 50m

Whole Life Carbon

Overview

The Mosque's embodied carbon is dominated by two main elements and materials, the concrete in the basement and foundations, and the timber superstructure elements. The basement was a planning requirement due to a large numbers of visitors who may otherwise park their cars in the nearby residential streets. Cambridge's ground conditions inferred a need for increased foundations and groundworks.

This building has higher walls (8m+) compared to typical buildings (c. 2.5-3m), and is predominantly one storey, meaning for the amount of built fabric there is less internal floor area to divide the total by in our assessment. This results in an unusual dynamic for calculating carbon impacts in relation to internal area that should be noted as compared to other typologies.

Whole life carbon benchmarking

There are limited benchmarks available for religious buildings. We have been able to make use of the recent NZCBS pilot limits for Worship and for Performance, although these are intended for use in 2030, so not strictly fair comparisons, given the building's completion in 2020. The building still performs well against these, with its Upfront Carbon at 90% of the Limit for Performance, and 33% higher than the 2030 limit for Worship buildings. Most likely if the basement had been possible to remove from the design, this would help make significant carbon-savings and improve the building's performance even further against these metrics.

Life cycle assessment results

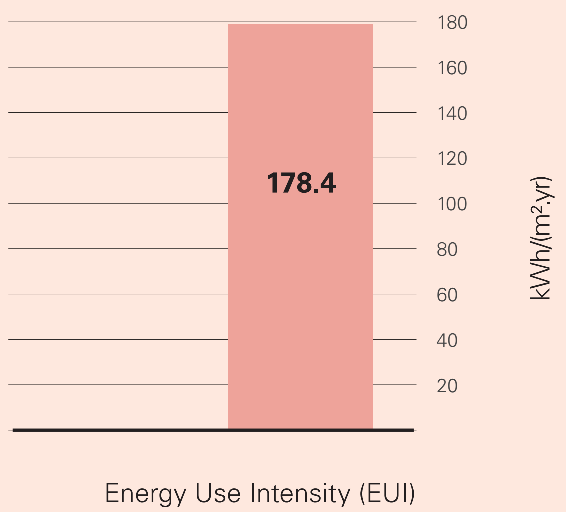
Life cycle stage	tCO_2e	$kgCO_2e/m^2$
Product stage (A1-A3)	2,491	508
Construction process (A4-5)	369	75
Upfront Embodied Carbon* (A1-5)	**2,860**	**584**
Upfront biogenic carbon (A1-5)	**-1071**	**-219**
Replacement (B4)	353	72
End-of-life (C1-4)	1,370	280
Embodied Carbon (A-C excluding B6 & B7)	**3,512**	**717**
Energy use (B6) (decarbonised**)	1,676	342
Water use (B7)	N/A	N/A
Total WLC (A-C)	**5,187**	**1,059**
Benefits and loads beyond system boundary (D)	-840	-171

* upfront biogenic carbon is not incorporated in Upfront Embodied Carbon. Sequestered carbon is only accounted for (ie deducted) in Embodied Carbon across A-C modules in line with best practice.

** we have adopted a decarbonised grid scenario for the Energy Use prediction. Refer to Methodology for full explanation.

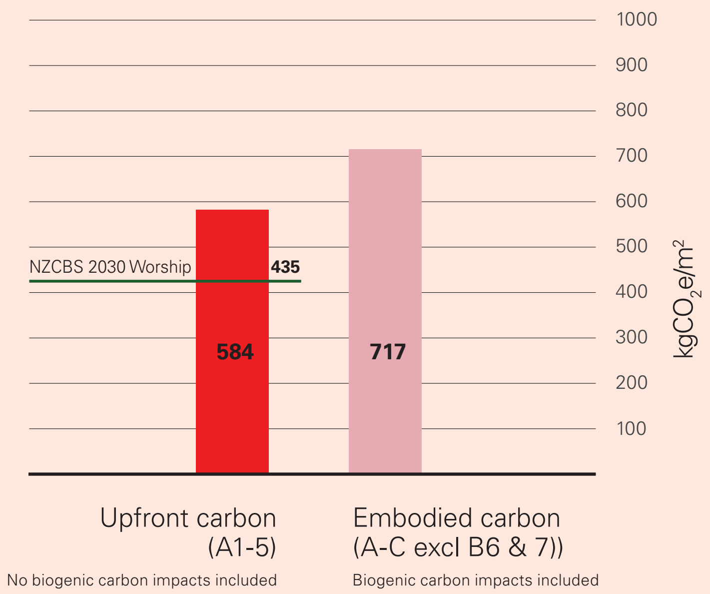
Energy Use Intensity (EUI)

There is no 'Worship' typology limit available for EUI in the NZCBS. As mentioned, the reduced internal floor area to fabric is likely an influence here. Worship buildings are notoriously challenging to service by virtue of their fluctuating capacity. This sector is one that generally does not contribute significantly to our national energy consumption. While improvements are likely possible in future religious buildings, there is also a need to balance with other priorities, such as quality of life.



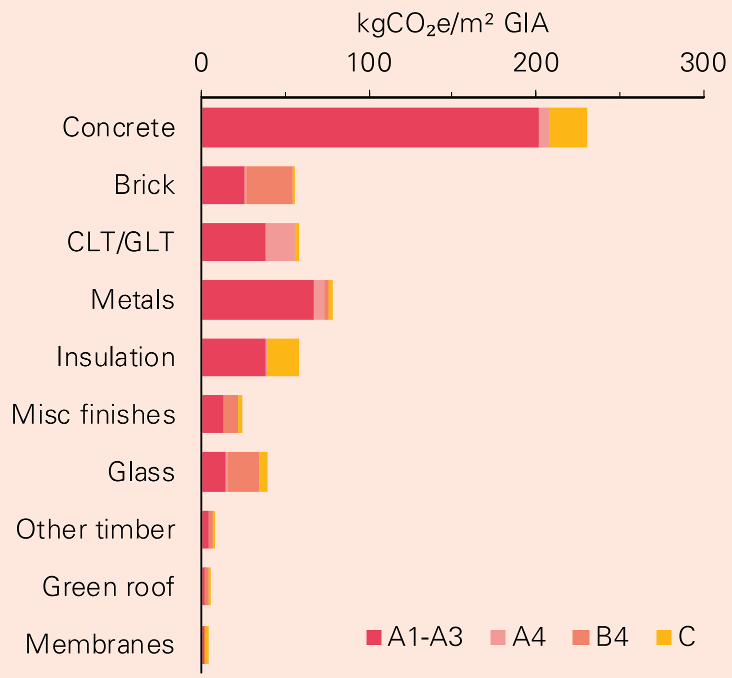
Embodied Carbon

Here we have benchmarked against the nearest comparator in the NZCBS (2024 Pilot) - for the 'General' category of 'Culture, Worship & Entertainment' Embodied Carbon Limits. There are no relevant RIBA 2030 or LETI available for this case study. The building exceeds the NZCBS 2030 target by 33%. However, with the building constructed a decade before the target is intended for this is still a good outcome.



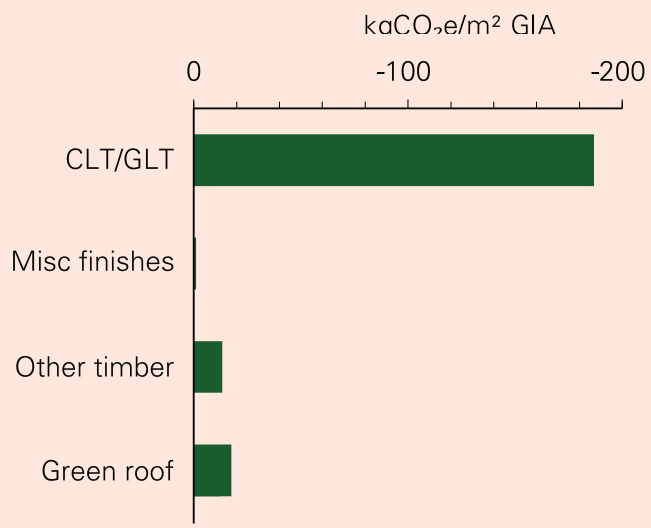
Embodied Carbon by material

Over the building's lifetime, the concrete/brick elements contribute a significant proportion of the overall carbon impacts. The CLT/GLT, while sizeable as part of the main above ground structure, is seen to represent a relatively low carbon impact over all life-cycle stages.



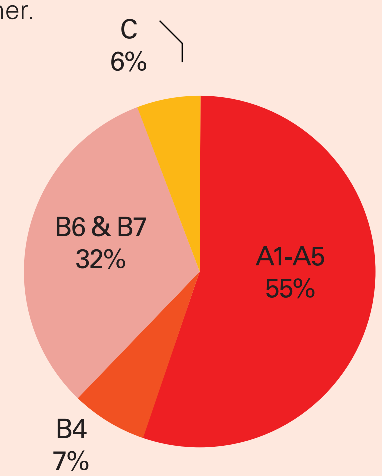
Upfront biogenic carbon by material

While a relatively small proportion of the embodied carbon impacts, there is a substantial upfront carbon sequestration in the CLT/GLT elements. Carbon will remain stored in these mass timber elements for the duration of their use, likely a long timeframe given the unlikelihood of the building being replaced. Religious buildings tend to remain in operation for very long lifetimes. We have also calculated sequestration associated with the green roof.



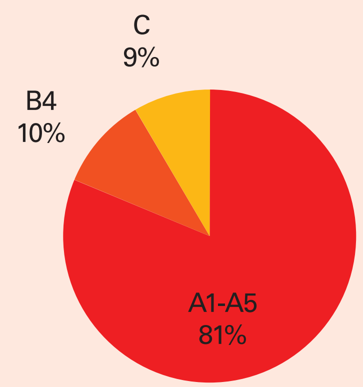
Whole life carbon (A-C)

Here the effects of sequestration are incorporated (i.e. the carbon stored in biobased products is deducted).
NB: The carbon pie charts are shown relative in scale to one another.



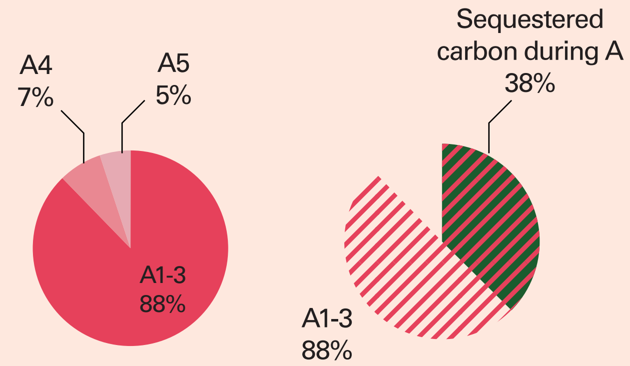
Embodied Carbon (A-C excl B6 & B7)

Here the effects of sequestration are incorporated. This is a typical scope used when benchmarking, with EUI typically benchmarked separately.



Upfront embodied carbon (A1-5) & biogenic carbon

When reporting upfront embodied carbon alone, the effects of sequestration cannot be incorporated. Shown below are the scale of biogenic carbon storage impacts as part of A1-3 as a point of additional information.



Quality of Life

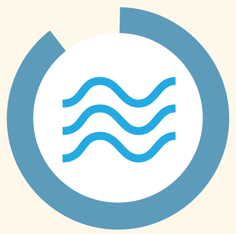
Internal condition monitoring overview

Monitoring devices were positioned in a range of locations in the building, in mostly front-of-house areas as well as an office. One monitor was misplaced during the study period, but we still had good coverage from the other devices. The building was designed for 1000 worshippers, however 1500-2000 people regularly visit the building, with more prayer sessions provided. It is interesting to analyse the building's performance in this context, where spaces and systems are being pushed to do more than they were originally designed for.

Generally, the spaces analysed in the Mosque are within healthy averages for VOCs, CO_2 and humidity levels and in most spaces for temperature. Occupancy fluctuates significantly throughout the day/night and throughout the year. CO_2 levels peak, before being purged by natural or mechanical ventilation. The same occurs for tVOCs except for the office space, a room which is set deep within the plan making natural ventilation difficult to achieve. This space is also most subjected to overheating, whilst the prayer hall, café and lobby remain within the comfort range 85% of the time. The office was not actually intended for this function - due to demand there are two more Imams on site than originally expected, which has led to a reorganisation of internal spaces.

Relative humidity is within the recommended range 90% of the time, ensuring the building is comfortable during the various activities and functions hosted throughout the Mosque's busy calendar.

90% are not at all or not very aware of noise outside the building



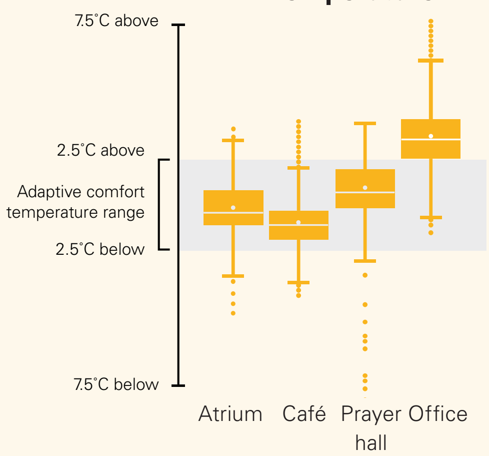
90% of occupants felt positive about the air quality

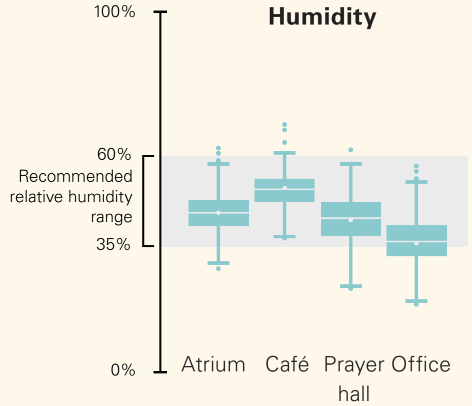
Internal condition monitor results

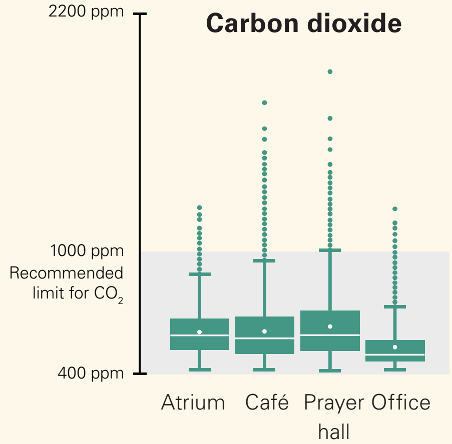
Category	Findings
Internal Temperature	Temperatures are well controlled in most areas, staying within the comfort range over 85% of the time. The office is an exception, being too warm, especially at night, likely due to an extra heat source.
Relative humidity	Relative humidity is well controlled, staying within the recommended range over 90% of the time, with occasional dryness during very cold weather.
Air Quality	The mosque's ventilation keeps CO_2 levels mostly within limits, with brief exceedances during peak times that quickly resolve. tVOC levels often exceed 250 ppb, peaking at night, especially in the office. Daytime ventilation quickly reduces these levels, minimising exposure risks.

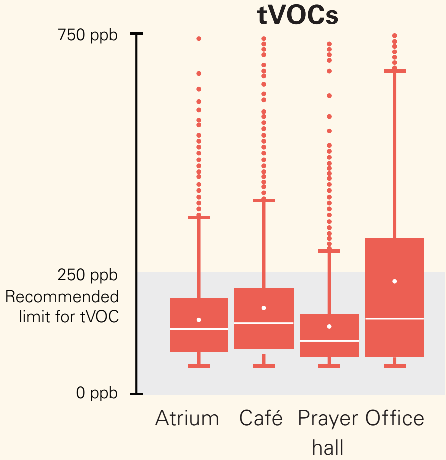
Internal condition benchmarking

Data represented for all measured hours across the monitoring period in 2022-24. The methodology section of this report gives further detail on recommended range evidence basis for each category.









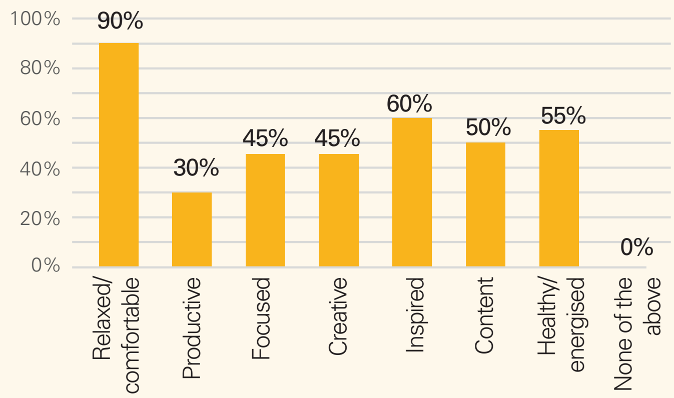
User experience overview

The feedback was resoundingly positive. Questionnaires were completed by 22 people using the mosque, considered statistically representative on the day visited. 90% of building users felt relaxed/comfortable whilst 95% were reminded of the natural world by the materials. A majority of respondents felt more calm worshipping in the mosque than other spaces because of the timber design, 70% felt the timber design influenced why they spent time there and 80% felt motivated to speak about the timber design to others.

90% of occupants were made to feel more relaxed and/or comfortable by timber features

95% of occupants are reminded of the natural world

Compared to other Mosques or other similar buildings, the timber features make me feel more...



What do you like about this building?

"Beautiful design that feels like an extension of the natural world"

"I feel uplifted and calm"

"you are being cosseted by nature"

"The architecture is in line with the spirituality. Matches the sense of inner peace"

Of all responses to this question, design, beauty and nature are strongly evident:

User experience survey results

Category	Findings
Satisfaction	The space is considered safe with 'children running freely' and the design is regularly likened to forests and flowers. Most feel 'Inspired' and 'Healthy'. Productivity is lower in reporting, at 30%, however this is not a particularly relevant aspect when analysing a place of worship apart for the team working there.
Meeting user needs	The timber design influenced why users spend time in the mosque (70%) and encouraged them to think more of the natural world (86%). 50% of users offered shortcomings limited to signage, public transport connections and parking. With this said, there is a bus stop directly outside the mosque and it is 15 mins walk from the main Cambridge Train station, so it is unclear what aspect of the public transport links those surveyed were not satisfied with. 73% of those surveyed travel to the building by car, suggesting the car park is being made use of.
Perceived impact on health and wellbeing	Building users felt 'calm' and 'connected to nature'. Timber design is recognised to make a positive impact on health and wellbeing, and to creating a 'relaxed/comfortable' feeling.
Comfort and indoor air quality	All users felt either neutral or positive about air quality. 65% of visitors were not sure how comfortable they were in winter and 31% felt it was slightly too warm in summer.
Sound	14% of users were aware of noise outside the building, 45% were not at all aware.
Lighting	94% are satisfied with the amount of daylight in the building.
Perceived control	Occupants appreciate 'large opening windows'.
Utility costs	N/A

Figure 50. Atrium & reception space with storage for shoes

Figure 51. Islamic garden with covered entrance area

Figure 52. Prayer hall with prominent 'trees'

Discussion

With this case study, we were interested that the **architecture is highly expressive** and fosters a **sense of biophilia**. We were also interested to see whether ornament and flourish with timber heightened quality of life, and whether the carbon impacts were still reasonable. The brief for Cambridge Mosque required the architects to consider the spiritual, beyond the merely pragmatic functional needs. The Islamic faith 'teaches its followers to take care of the earth' and the architects have taken this environmental ethos through to their selection of materials and passive design strategies.

Here, the mass timber is probably at the most visually expressive of the five case studies - beyond being a flat surface. The building was conceived as 'a calm oasis within a grove of trees'. Feedback from visitors suggests that the architecture has become of the trees, with one respondent saying **'it feels like we are in a forest**'. Biophilia is clearly at the heart of the design of this building, so it is unsurprising that the Quality of Life findings suggest a strong connection between the timber structure and feeling relaxed/comfortable and 95% of **visitors reminded of the natural world**. **80% of people talk about the timber architecture with other people**. It is interesting to consider the wider reach and potential impact these conversations might be having.

There are not many worship building relevant benchmarks that we can compare its whole life carbon performance to. In relation to the 2030 NZCBS Worship limit, the building is some 33% higher in embodied carbon. Some of this will be possible to address in future similar buildings by seeking to eliminate basement car parking. It is disappointing that wider public and active transport systems are not sufficient to have enabled the planners to have allowed the architects to have done away with the on-site car parking requirement, as without this the building would have been a very light impact in relation to net zero carbon benchmarking. This one decision's significant impact goes to show the **limitations of timber design alone** at decarbonising the built environment, and emphasises the role that planning and wider policy making has to limit carbon reductions in any particular scheme, alongside our own individual behaviour patterns in what modes of transport we adopt. It is also notable that the building's unusually tall floor to ceiling heights will be skewing the finding as compared to area based metrics. Perhaps further consideration is needed as to appropriate benchmarks for this rather exceptional typology.

On our repeated visits to the building, we have been able to see the mosque at very busy moments – inadvertently choosing to visit during peak times. The building is so popular that busy prayer times can see the atrium entrance being used as overflow prayer space. We met visitors coming from all over the UK and beyond on tours of mosques who had heard from word-of-mouth how beautiful and spiritually uplifting this particular building is. We see from this building the potential for architecture that derives inspiration from nature and supporting an enhanced connection with the wider environment has to resonate with a visiting public. Visitor after visitor remarked on the uplifting power of the space.

This is a popular building, with the timber one of the reasons attributed. The building has 50-100% more worshippers visiting than it was designed to accommodate. The building systems would benefit from a more detailed review in light of actual occupancies as compared to design assumptions, as **popularity can make for unexpected building performance patterns**. For instance, 31% of people felt slightly too warm in Summer, which tallies with our findings from monitoring data. It is unclear however if the source of heating is from more people using the building, or if this is due to external temperatures being higher than expected. There is real challenge in developing systems given the very dynamic **nature of extreme fluctuations in the spaces' use**.

It is interesting to consider that people remove their shoes en masse in entering this building and how that might affect their comfort year-round. 65% of visitors were 'not sure' how comfortable they were in winter months, despite no obvious issues seen in our monitoring findings. **How inclusive are the benchmarks/best practice guides for comfort?** Often we talk about gender-based limitations, and in this building certainly gender influences user behaviour given the segregation of the congregation physically. Here we see the need to develop POEs with respect to cultural inclusivity. We would like to see more worship buildings' POEs made available to inform sector-relevant targets and approaches.

Key takeaways

- This building demonstrates **very strong connections between visitors to this building and the timber architecture**. We would suggest the **quality of life enhancements to be significant here**, including connection to nature**.**
- While the **embodied carbon performance is good**, the basement makes a significant contribution to the embodied carbon impacts. This shows that there is **only so much that can be achieved through adopting a mass timber system alone** and the role that planning plays in affecting outcomes.

To be explored further

- **NZCBS limits could be developed for Worship** for EUIs in the future. Considering the taller-than-usual floor to ceilings would be beneficial in developing these limits.
- It would be helpful to have a **rule of thumb carbon impact for basements** that could be used in early design stages to demonstrate to the scale of impact arising from them.
- The role of **cultural practices in buildings as altering perceptions of comfort** could be interesting to explore in wider POE practices.

6 Orsman Road

Figure 53. 6 Orsman Road north elevation viewed from Regent's Canal (Photo Ed Reeve)

Figure 54. 5th floor break-out/co-working space. An internal condition monitor was located on the shelving unit seen right (Photo Ed Reeve)

Project Information	
Building type	Workplace
Location	Hackney, London
Date completed	2020
Gross internal area	4,678 m²
Mass timber application	CLT intermediate floors, core and roof structure. In direct hybrid with steel.
Architect	Waugh Thistleton
Structural engineer	GDC Partnership & Enginuiti; Ramboll
M&E	Mendick Waring; Ramboll
Fire consultant	International Fire Consultants; OFR Consultants

6 Orsman Road is a six-storey commercial workspace building designed with a contemporary, open layout. On the ground floor, a communal café and an open workspace extend toward Regent's Canal, creating a welcoming environment for collaboration. Levels one through four feature workspaces on both the north and south sides, divided by two stair cores and flexible meeting areas with non-structural partitions. The fifth and top floor offers a spacious shared roof terrace alongside meeting rooms and a communal area.

The interiors embrace a minimalist aesthetic, showcasing exposed CLT surfaces and natural materials such as clay plaster and linoleum. Offcuts from the CLT structure are creatively repurposed into furniture and stair components. Cellular beams allow for efficient MEP integration within the limited ceiling height.

The building uses an air source heat pump and 56 photovoltaic panels for on-site renewable energy. Heating and cooling are provided by a VRV system with exposed fan coil units connected to grilles. Fresh air is supplied via local MVHR units.

Constructed primarily from prefabricated systems, the building features a largely bolted assembly method that promotes circularity at end-of-life.

Whole Life Carbon

From modules A1-A3, CLT contributes to 10% of the embodied carbon, whilst accounting for the same proportion of building weight. Metal, mostly in the steel frame, accounts for 35% of the embodied carbon from A1-A3 despite representing just 9% of the building weight. At end-of-life it is very likely that much of the building structure could be repurposed, so the end-of-life carbon scenario is conservative at present.

Since green roofs and fibre cement cladding panels (finishes) are to be replaced during the building life-cycle, they make the most significant contribution to module B4, along with glazing systems, internal doors and floorings (finishes). Transport emissions from module C are almost entirely attributed to concrete, in its journey to landfill, followed by steel in preparation for recycling. These end-of-life scenarios are conservative, with the reality that it is unlikely that concrete would end up in landfill, however we have relied upon product EPDs for end-of-life assumptions.

Benchmarking

Workplace typologies are well benchmarked by LETI, RIBA and the pilot Net Zero Carbon Building Standard (NZCBS). This building performs well against all benchmarks for embodied carbon, surpassing all limits/targets. The Energy Use Intensity could potentially be improved upon, at 5% beyond 2021 ‘good practice’ according to the RIBA’s 2030 Climate Challenge. Energy Use Intensity is possible to improve upon while buildings are occupied and this could be an area to be continually explored and refined.

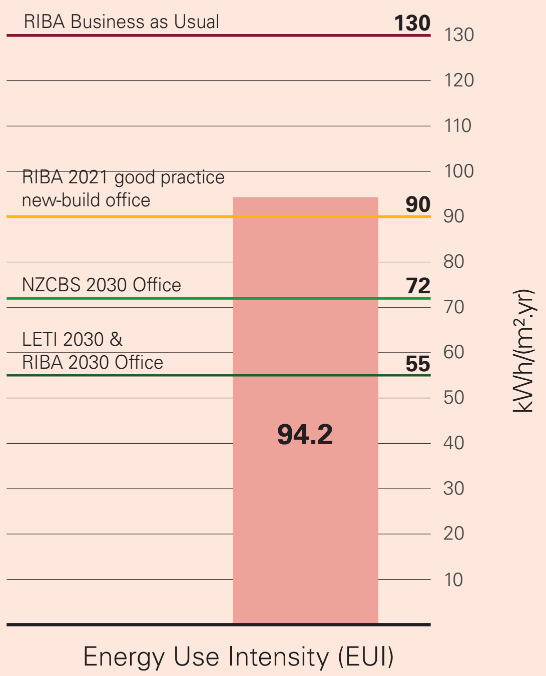
Life cycle assessment summary:

Life cycle stage	tCO_2e	$kgCO_2e/m^2$
Product stage (A1-A3)	1,521	325
Construction process (A4-5)	238	51
Upfront embodied carbon* (A1-5)	**1,759**	**376**
Upfront biogenic carbon (A1-5)	**-743**	**-159**
Replacement (B4)	119	25
End-of-life (C1-4)	840	180
Embodied carbon (A-C excluding B6 & B7)	**1,976**	**422**
Energy use (B6) (decarbonised**)	847	181
Water use (B7)	9	1.9
Total WLC (A-C)	**2,831**	**605**
Benefits and loads beyond system boundary (D)	-509	-109

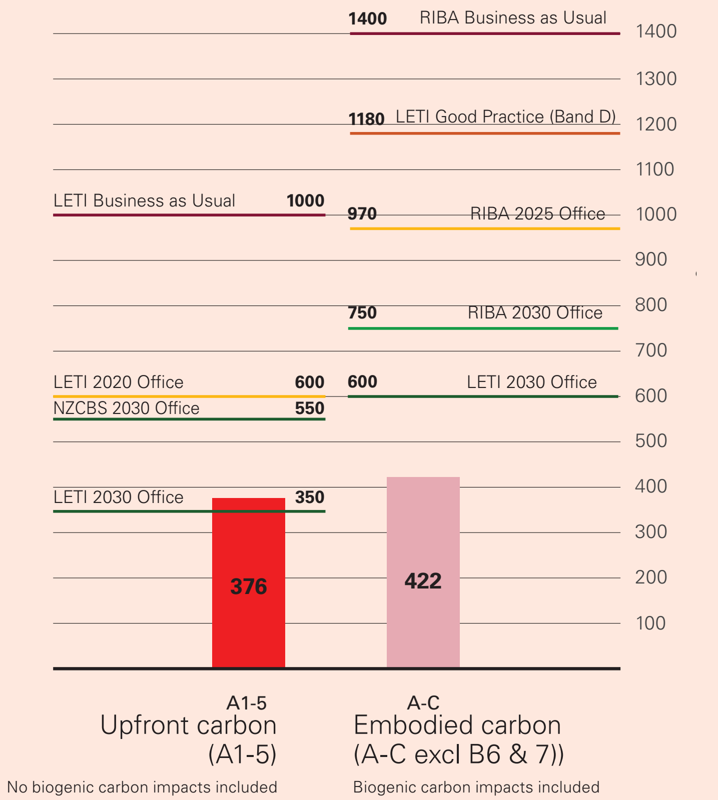
* upfront biogenic carbon is not incorporated in Upfront Embodied Carbon. Sequestered carbon is only accounted for (ie deducted) in Embodied Carbon across A-C modules in line with best practice.

** we have adopted a decarbonised grid scenario for the Energy Use prediction. Refer to Methodology for full explanation.

Energy use intensity (EUI) benchmarking

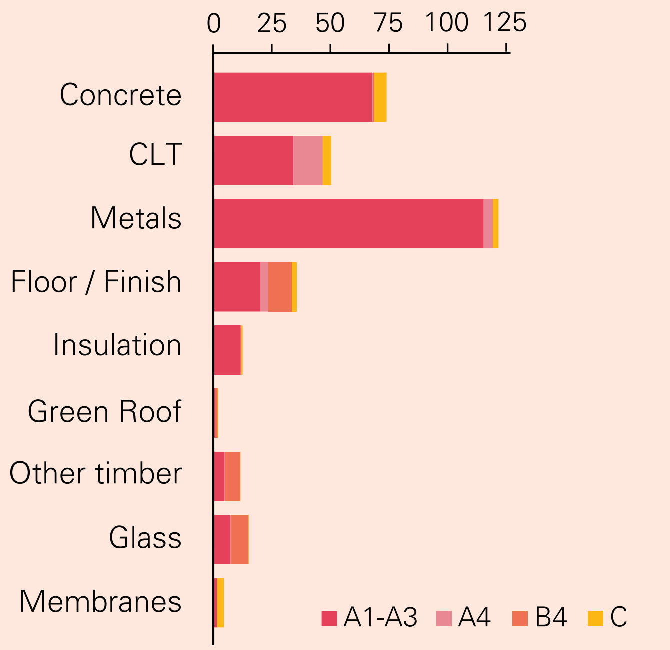


Embodied carbon benchmarking



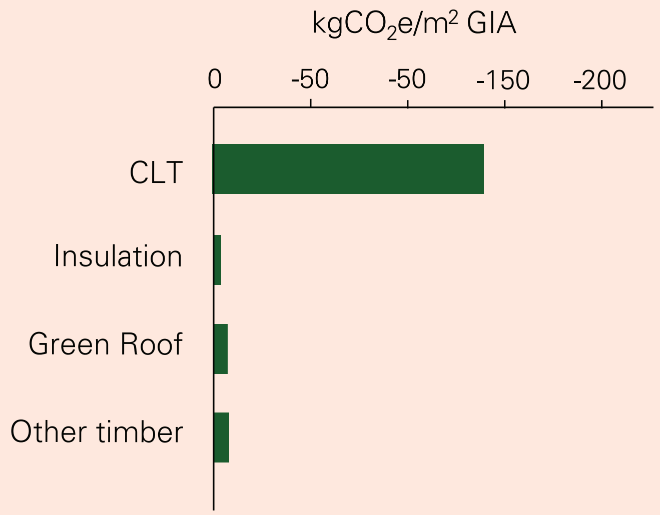
Embodied Carbon by material

Here the timber elements can be seen to be relatively small carbon impacts as compared to concrete and most significantly, metals. The steel frame is designed to be largely demountable at end-of-life with bolted connections, so it would be hoped that much of this resource would be continued to be useful in future lives beyond use in this building.



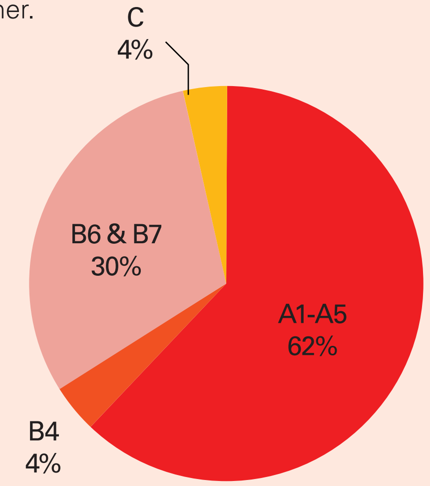
Upfront biogenic carbon by material

The vast majority of sequestration is within the CLT structure. This means that most of the carbon sequestered should be held in place for a relatively long period of time, as the structure is unlikely to undergo significant modification as compared to shorter lived building elements.



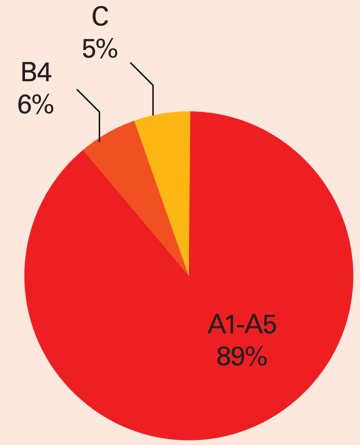
Whole life carbon (A-C)

Here the effects of sequestration are incorporated (i.e. the carbon stored in biobased products is deducted). NB: The carbon pie charts are shown relative in scale to one another.



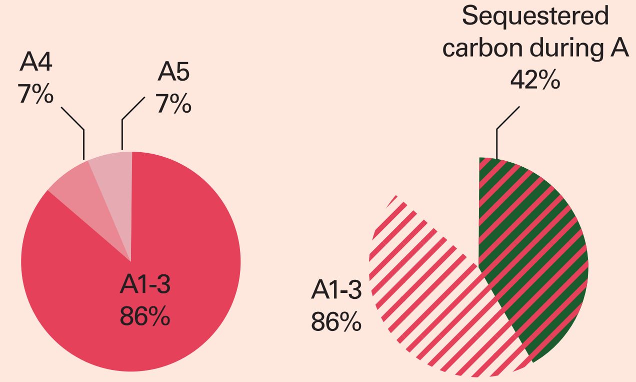
Embodied Carbon (A-C excl B6 & B7)

Here the effects of sequestration are incorporated. This is a typical scope used when benchmarking, with EUI typically benchmarked separately.



Upfront embodied carbon (A1-5)

When reporting upfront embodied carbon alone, the effects of sequestration cannot be incorporated. Shown below are the scale of sequestration impacts as part of A1-3 as a point of additional information.

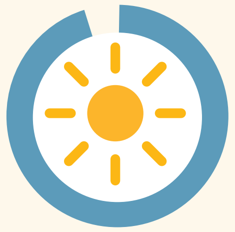


Quality of Life

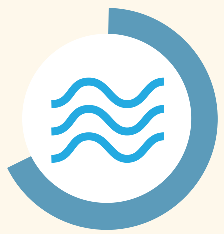
Internal condition monitoring overview

The building is very well ventilated, rarely if ever exceeding recommended CO_2 levels, despite periods of high occupancy. tVOCs peak in early afternoons, likely resulting from higher occupation and human activity building up over the course of the day.

Within the period studied, temperatures were generally slightly higher than recommended levels in both summer and winter, with variety recorded across the building, which is well shaded to the south and substantially glazed to the north, east and ground floor areas.



94% of occupants felt satisfied about the amount of daylight in the building

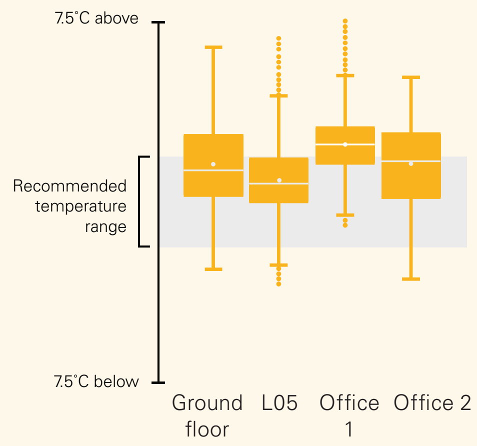


80% of occupants felt positive about the air quality

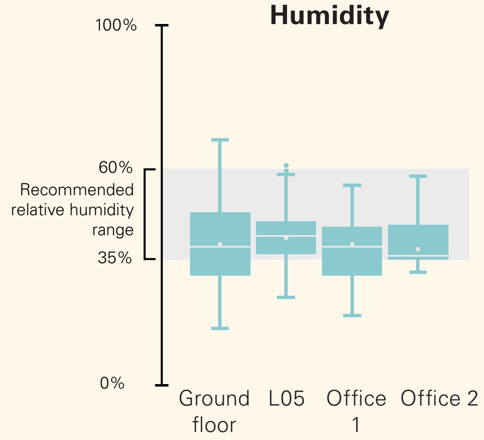
Internal condition benchmarking

See the Methodology chapter for more information on source data and interpreting box plot charts.

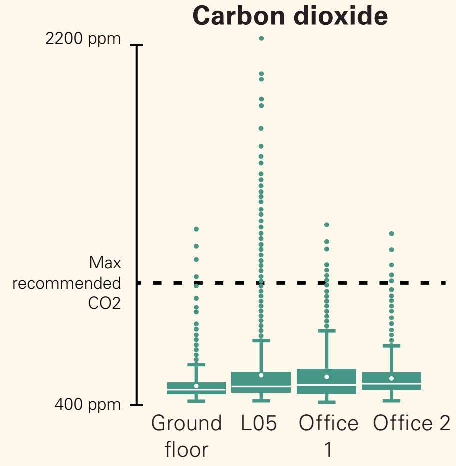
Temperature



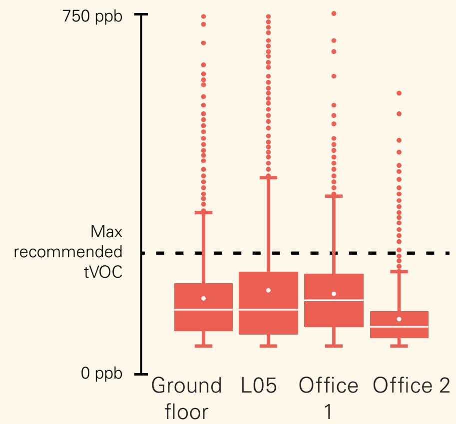
Humidity



Carbon dioxide



tVOCs



Internal condition monitor results

Category	Findings
Internal Temperature	Temperatures often exceeding the comfort range, especially in Office -1, where it's above the range 60% of the time. The likely fixed 23°C setpoint could be reviewed alongside systems, as the temperature is recorded higher than recommended levels in winter and occasional temperatures over 30°C during heat waves.
Relative humidity	Relative humidity levels are low, particularly in winter.
Air Quality	Carbon dioxide levels were excellent, with exceedances of 1000 ppm under 1% of the time. There may be potential to review the ventilation systems, as this might suggest opportunity to reduce energy use and reduce the ventilation. tVOC levels sometimes exceeded 250 ppb, especially during peak occupancy, likely due to human activities and pollutants from the central London environs. Increasing ventilation isn't recommended without identifying specific VOC sources.

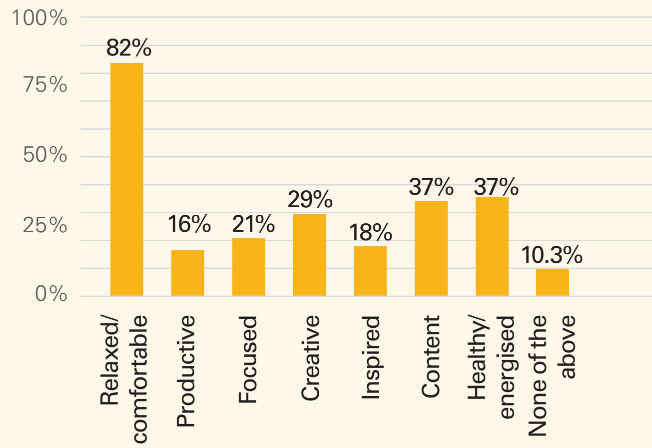
User experience overview

Building users commonly remark on the ample natural light and a sense of warmth throughout the space. Although Airthings devices recorded higher temperatures in the summer, the majority of occupants report feeling comfortable (50%), with only a small portion finding it slightly warm (7.4%). Additionally, 94% of users are satisfied with the level of natural daylight. Among those who feel the building's materials evoke the natural world (54.4%), all also report experiencing improved focus.

82% of occupants were made to feel more relaxed and/or comfortable by timber features

61% have spoken about the timber design with others

Compared to other office buildings I've worked in, the timber features of this building make me feel more...



What do you like about this building?

"The smell of natural wood!"

"The feeling of warmth from the glass and wood"

"Natural materials, lots of daylight"

"So much. Its design, its materiality, its emotional warmth... its sense of place"

Cleanliness, the roof terrace and the 'modern' nature of the building are perceived strongly, with wood featuring fairly prominently across all responses to this question:

User experience survey results

Category	Findings
Satisfaction	Occupants greatly appreciate ground floor and roof-top communal spaces. Variety of working places are held in high regard. Few staff reporting feeling more productive but 84% are more relaxed.
Meeting user needs	Occupants greatly appreciate ground floor and roof-top spaces. Variety of working places are held in high regard. Few staff feel more productive but 84% are more relaxed.
Perceived impact on health and wellbeing	Staff and cleanliness are regularly mentioned, and bathroom, shower and café facilities are all liked. Many occupants are motivated to ensure the building is well kept and 61% of occupants speak about the timber design with others.
Comfort and indoor air quality	82% of people feel the building has a positive impact through increased relaxation. 26% feel that it's slightly cold during the summer. The rest feel it is comfortable (50%) or slightly too warm (7.4%). The large majority of respondents slightly too cold are female, pointing to gender inequity in thermal comfort.
Sound	61% of people are aware, and 13% are very aware of others in the building. 82% are not very aware (45%) or not at all aware (35%) of noise outside the building.
Lighting	94% are satisfied with the amount of daylight in the building.
Perceived control over (above)	Occupants appreciate 'large opening windows'.
Utility costs	N/A

Figure 55. Open plan office space and meeting rooms (Photo Ed Reeve)

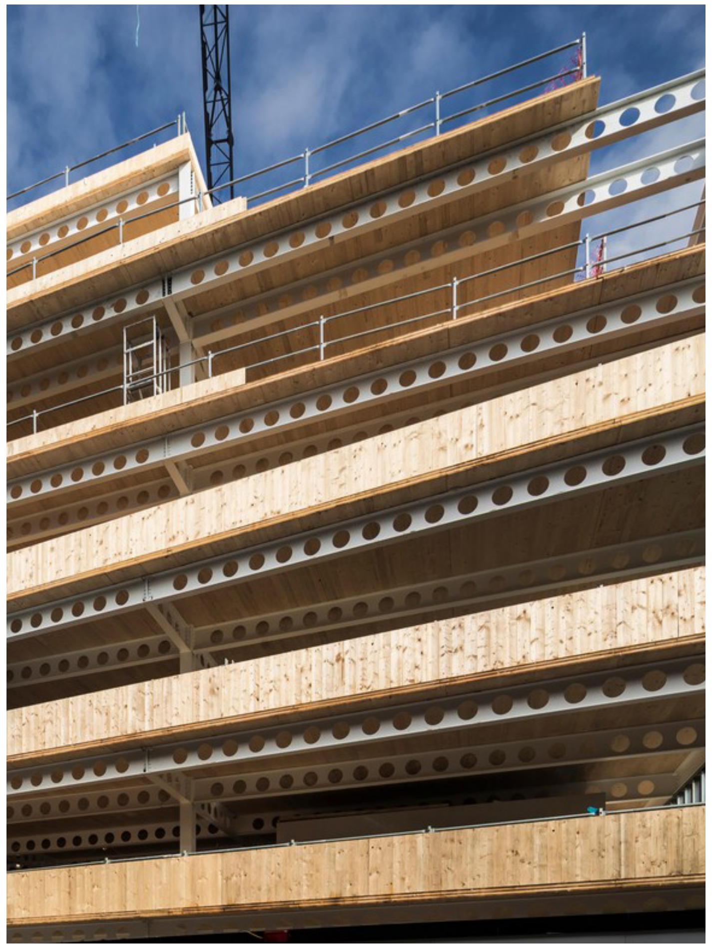


Figure 56. 6 Orsman Road under construction (Photo Tim Crocker)

Figure 57. Stairwell featuring prominent timber finishes (Photo Ed Reeve)

Discussion

The **UK commercial market has faced a post-COVID shift,** with remote and home working significantly reshaping workplace culture. There is now a strong preference for high-quality, best-in-class spaces that prioritise amenities and sustainability, with a particular focus on energy efficiency, according to OKTRA. Demand for new workspaces emphasises the value of sustainability, positioning architects well to meet these expectations with innovative, sustainable designs.

All five case studies incorporate hybrid mass timber systems to some degree. This project, however, combines mass timber with a steel frame to create a **true hybrid construction**, performing **exceptionally well in embodied carbon metrics compared to industry standards**. Designed for deconstruction and reuse, the building embraces **end-of-life circularity**, an area that current WLC practices do not adequately address.

As a flexible private workplace, 6 Orsman Road must remain adaptable to meet the needs of diverse tenants while fulfilling the developer's objectives. Flexibility is key in terms of lease length, office size, layout, design, and all-inclusive services. **Tenant turnover is a significant contributor to whole-life carbon impacts in commercial buildings**; at Orsman Road, AHMM's study of the "Carbon Cost of Cat A" helped shape a sustainable approach. The mass timber and steel hybrid structure is left exposed, minimising the need for standard fit-out layers like suspended ceilings and instead integrating MEP systems visibly within perforated steel beams, reducing carbon impacts over repeated life cycles. This flexible model also limits waste, as tenants have less freedom to alter workspaces compared to traditional setups.

Embodied carbon benchmarking has shown that Orsman Road's performance even **out-performs 2030 targets/limits**, showcasing that **mass timber offers a ready, viable solution to meeting these targets already.** This also indicates that future standards could be more ambitious. A shift in developer expectations for workplace design in a decarbonised future seems both feasible and necessary.

Once connected with the building management team and security desk, our research team found repeated visits to the building relatively straightforward by virtue of established procedures for visitors in workspace buildings. We also were able to interview and survey a large number of building users. Internal condition monitors did show higher temperatures than recommended levels in some summer periods, however our occupant experience survey showed that building users were still comfortable by and large. This shows that while measured temperatures can fluctuate, individuals have other means of control to thermal comfort, e.g. removing a jacket, and that it is best to accompany measured conditions alongside user experiential feedback. There is perhaps opportunity to reduce energy use via a servicing review.

The "honest interiors" prominently feature **exposed mass timber surfaces alongside clay and other biobased materials**. While only 16% of respondents reported feeling more productive due to their environment, a substantial 82% noted improvements in wellbeing and comfort. Among these, 89% expressed an enhanced connection to nature, highlighting a strong relationship between wellbeing, comfort, and nature. These findings may encourage us to **challenge traditional notions of productivity**, as academic research consistently indicates that enhanced wellbeing—such as comfort and connection to nature—directly supports increased productivity. This suggests a potential for more sustainable work patterns that lower the risk of burnout. According to the Oxford Wellbeing Research Centre, there is a clear link between subjective wellbeing and productivity, while the WGBC reports that **biophilic design can boost office productivity** by 8%.

We believe further research is needed to explore productivity levels in mass timber buildings and the interrelationship between quality of life and productivity in these settings in more depth. For instance, businesses that have relocated to timber buildings could provide valuable data on financial performance, staff turnover, and sick leave, shedding light on any impacts upon productivity. This highlights a limitation of our study, as productivity was not a primary research question we intended to explore, yet it remains critical in the commercial workspace sector.

Key takeaways

- The building **significantly outperforms industry benchmarks for embodied carbon**, highlighting the potential mass timber hybrid systems offer to support decarbonisation today.
- The design of the building emphasises **flexibility and adaptability, which may further reduce carbon emissions** over a whole life as compared to typical office design approaches.
- Occupants report **improvements in quality of life/wellbeing**, with a strong majority feeling an **enhanced connection with nature.**

To be explored further

- Further research could focus on **impacts of biobased materials on productivity** and effects on the economic success of businesses occupying timber/biobased buildings, utilising businesses' own data such as attrition, sick leave and financial performance.
- Exploring the **potential for circular steel in hybrid structures** could reveal further opportunities for reducing carbon impacts.
- Examining the **commissioning of Building Management Systems (BMS) in office environments** in relation to occupant comfort may enhance operational efficiency and sustainability.

Figure 58. Rye Apartments from Peckham Rye Park

Figure 59. Kinsale Block west elevation

Rye Apartments

Project Information	
Building type	Residential
Location	London
Date completed	2020
Gross internal area	880 m²
Mass timber application	CLT/GLT external walls, internal walls, intermediate floors, roofs and core
Architect, Main Contractor & Developer	Tikari Works
Structural engineer	Webb Yates
M&E	Syntegra

Rye Apartments is a housing scheme of ten apartments set across two buildings (three- and four-storeys each). Tikari Works acted as both architect, main contractor and developer of this scheme, an unusual approach in the UK market.

The building forms the termination of an residential block, overlooking Peckham Rye park. The housing mix consists of four duplex 3-beds, four 2-beds and two 1-beds. Each home has private outdoor space. The ground floor is positioned partly below ground level. With a sloping site condition, reinforced concrete walls form a plinth supporting the timber superstructure above.

Mass timber elements are very visible in the interiors, with expression on walls and ceilings tying in with a wood-based interior design palette. The timber interiors can also be appreciated from the street by passers-by via the windows, particularly in evenings when the building is illuminated from within. The building heating demand is minimised by insulation and high levels of airtightness and met through a programmable zoned underfloor system. Ventilation is through a whole-house MVHR system. Electricity demand is partially met by solar PV panels.

Ground Floor Plan

NB: Position of internal condition monitors not shown to respect privacy of the resident whose home we studied. The devices were placed in the main bedroom and in the living space. They continuously monitored via a direct wifi connection.

SCALE: 1:250 — 0 1 5 10 25m

Whole Life Carbon

As both developer and contractor, the architects provided a comprehensive building inventory for the LCA. Mass timber is used extensively throughout the building and stores a significant amount of carbon. Carbon sequestered in the building as a whole system is equivalent to almost all emissions of the building from modules A1-5. The mass timber is left exposed and left as final finish where possible, meaning that low quantities of additional materials are applied. Where additional finishes are used, there is considerable use of further timber. Externally, cladding also is mostly timber, providing further carbon storage while the building elements are kept in use.

The building performs impressively against particularly the 2030 Embodied Carbon targets/limits. The site's existing level condition involved use of concrete structure to the ground floor as retaining walls. If built in a flatter site context, even further carbon savings could be made with a similar approach to building design.

Whole life carbon benchmarking

Residential typologies are well benchmarked by LETI, RIBA and the pilot Net Zero Carbon Building Standard (NZCBS). The benchmarks are generated by establishing 'business as usual' figures from a data set of assessments within the industry and applying percentage reductions over time. We can see the building's performance as compared to Embodied Carbon is impressive, below the RIBA 2030 Residential benchmark and very close to the NZCBS 2030 limit.

For EUI the performance is just under 6% higher than RIBA's 2025 residential target, which is a good level of performance considering the building was designed and constructed in 2020.

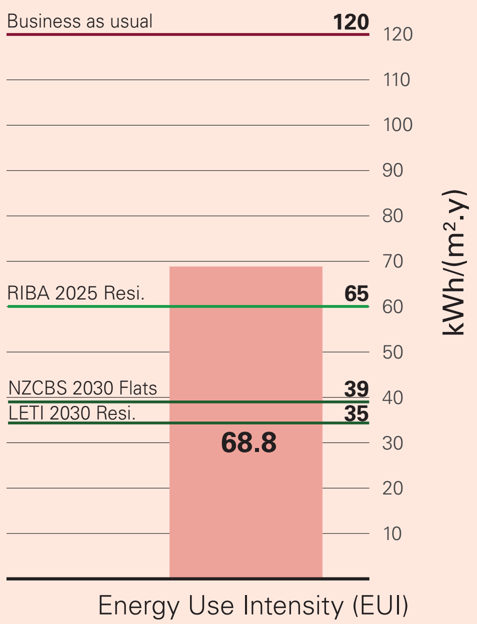
Life cycle assessment results

Life cycle stage	tCO_2e	$kgCO_2e/m^2$
Product stage (A1-A3)	279	317
Construction process (A4-5)	72	82
Upfront embodied carbon* (A1-5)	**350**	**398**
Upfront biogenic carbon (A1-5)	**-296**	**-336**
Replacement (B4)	32	36
End-of-life (C1-4)	322	366
Embodied carbon (A-C excluding B6 & 7)	**408**	**464**
Energy use (B6) (decarbonised**)	495	562
Water use (B7)	4	5
Total WLC (A-C)	**907**	**1,031**
Benefits and loads beyond system boundary (D)	-180	-205

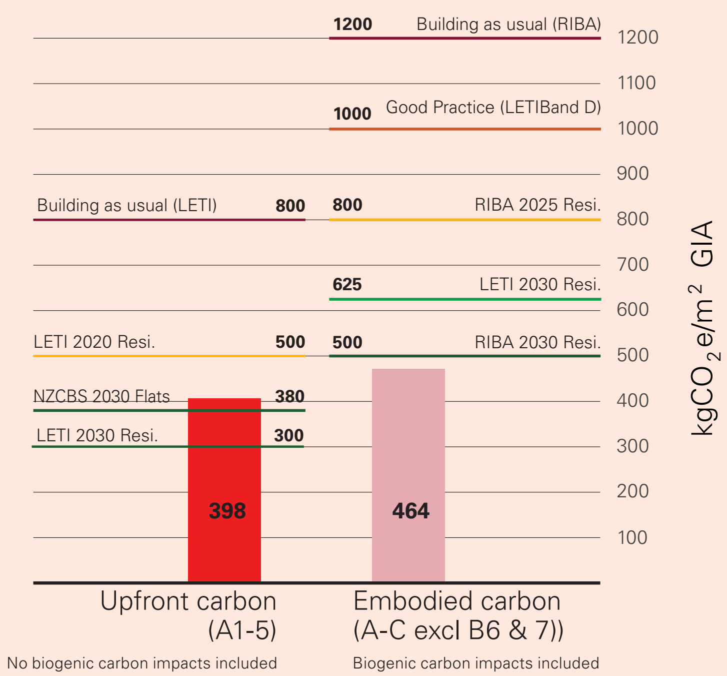
* upfront biogenic carbon is not incorporated in Upfront Embodied Carbon. Sequestered carbon is only accounted for (ie deducted) in Embodied Carbon across A-C modules in line with best practice.

** we have adopted a decarbonised grid scenario for the Energy Use prediction. Refer to Methodology for full explanation.

Energy Use Intensity (EUI)

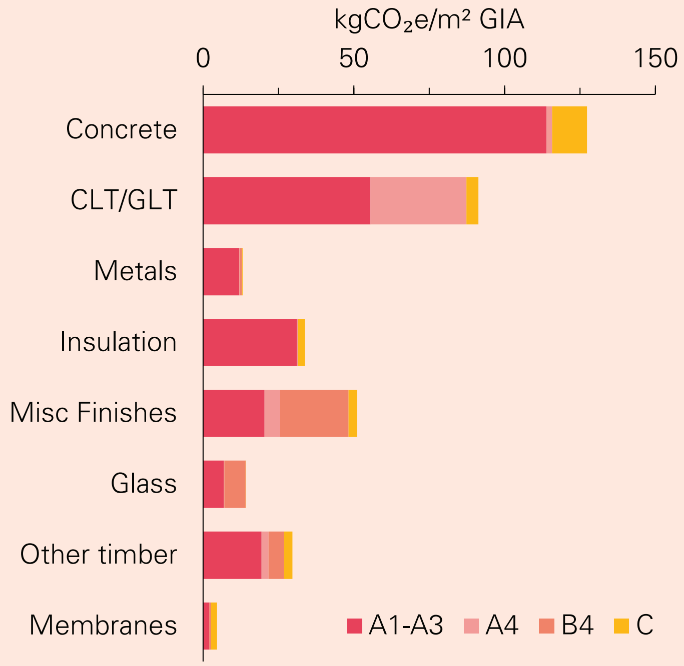


Embodied Carbon



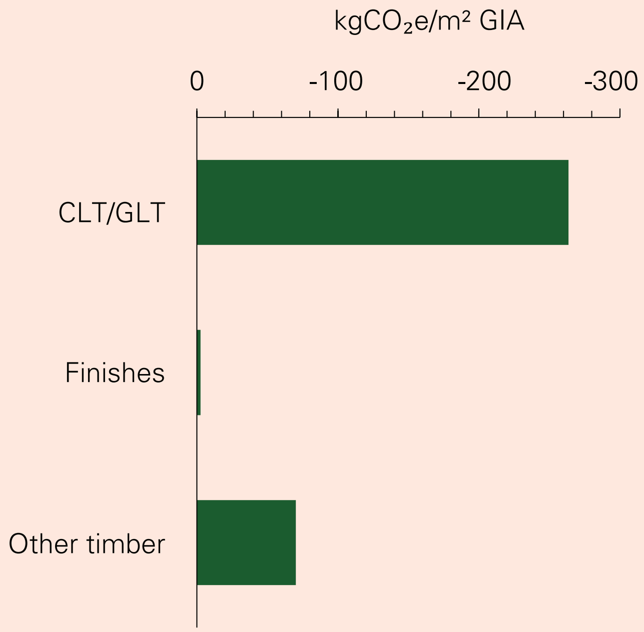
Embodied Carbon by material

The mass timber elements contribute the significant, but not majority, proportion of the carbon impacts over the building's whole life. The concrete foundations and ground floor structure are the largest contributor. Misc. finishes products contribute a significant proportion of the remaining emissions, with a higher B4 contribution. This reflects the replacement of finishes over a building's whole life.



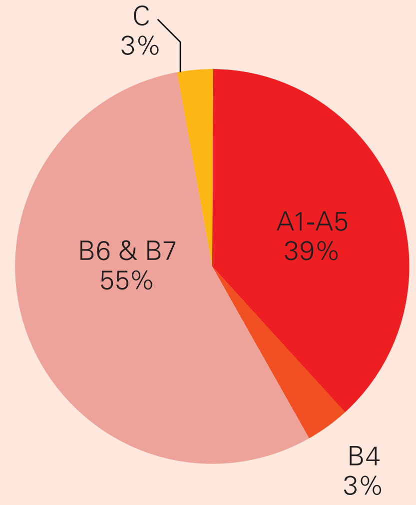
Upfront biogenic carbon by material

Mass timber elements sequester a significant proportion of the overall sequestration (78%). There is a fairly substantial contribution from Other Timber elements in the construction too. Finishes' contribution is relatively low, in part owing to the significant exposure of mass timber as final finish. Insulation is a missed opportunity for sequestration potential.



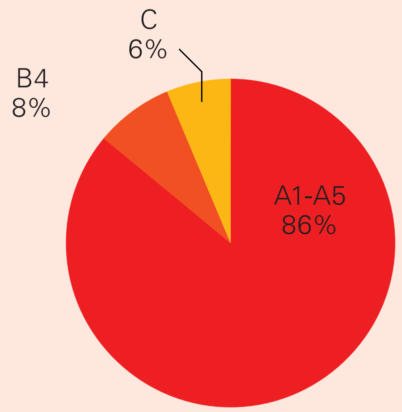
Whole life carbon (A-C)

Here the effects of sequestration are incorporated (i.e. the carbon stored in biobased products is deducted). NB: The carbon pie charts are shown relative in scale to one another.



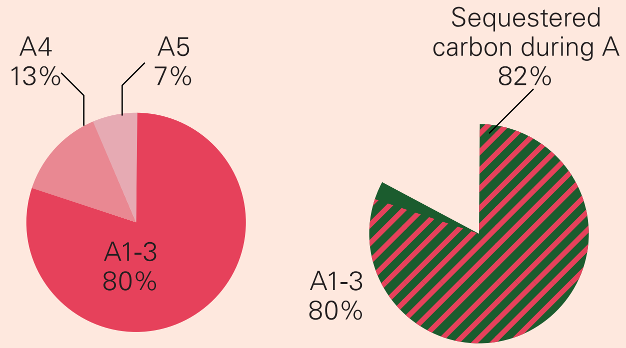
Embodied Carbon (A-C excl B6 & B7)

Here the effects of sequestration are incorporated. This is a typical scope used when benchmarking, with EUI typically benchmarked separately.



Upfront embodied carbon (A1-5)

When reporting upfront embodied carbon alone, the effects of sequestration cannot be incorporated. Shown below are the scale of sequestration impacts as part of A1-3 as a point of additional information. Here we see significant carbon sequestration occurring via CLT.



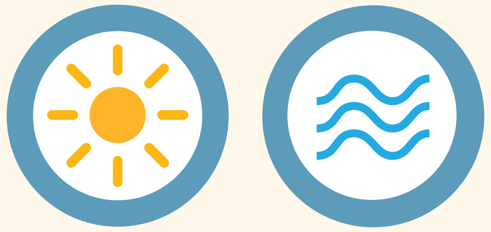
Quality of Life

Internal condition monitoring overview

One resident agreed to have two monitoring devices placed in their home, connected directly to their WiFi hub. This was the only case study where we did not need to make repeated visits for syncing the monitoring devices and we found the devices worked best in this setting with continuous data throughout the monitoring period. However, the resident did end their tenancy during the study duration. This represents a decent sample of the ten homes therefore being monitored, at 10% coverage, although we would have ideally liked to monitor more homes from a range of building locations.

We found in our engagement with the community living in this building that residents were uncomfortable with the idea of monitoring in general and the perceived potential of burden it might bring. For internal condition monitoring, the limited sample size is less of a concern than the quality of life component (right) as the internal condition monitoring aspect of the study is non-subjective.

From the data we collected, VOCs and CO_2 levels are consistently within healthy ranges. Temperatures are on the higher side in summer months in both recorded rooms, with humidity at the lower end of recommended levels.



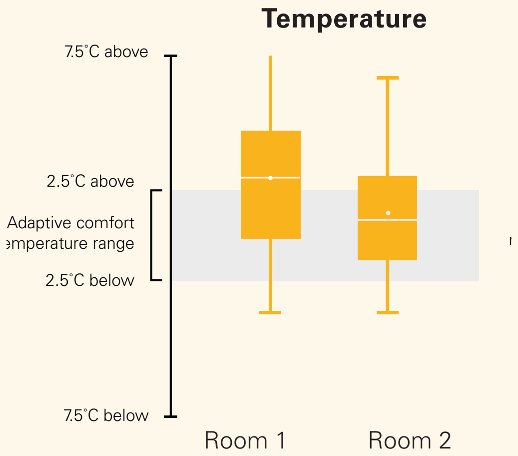
The occupant we surveyed was satisfied with levels of daylighting and air quality in the building

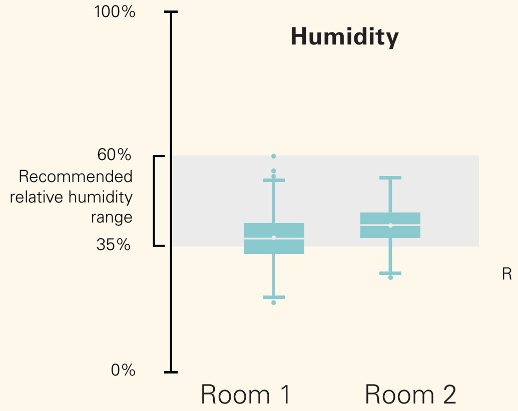
Internal condition monitor results

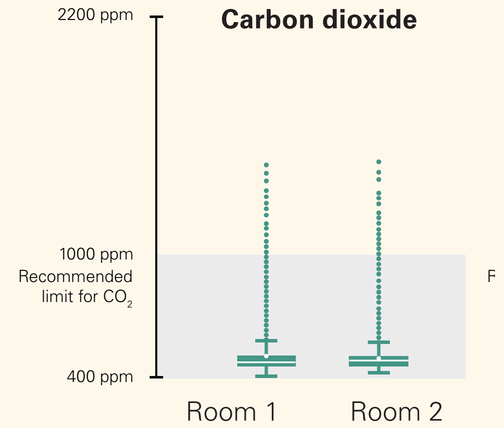
Category	Findings
Internal Temperature	Both spaces experienced overheating, with room 1 occasionally reaching over 35°C. It is not known what the resident's approach to ventilation was and if there is opportunity to improve this with better management of controls available to them, so further review is encouraged. During colder weather/the heating season, both rooms remain comfortable.
Relative humidity	Relative humidity is generally low, and at most times towards the dry end of the recommended range.
Air Quality	The air quality in the apartment presented is generally good. CO_2 levels exceed the recommended 1000 ppm mainly during occupied periods in the heating season when windows are closed. Overall, CO_2 levels are above 1000 ppm just over 1% of the time and around 4% during the heating season, which is acceptable. tVOC concentrations are slightly elevated, exceeding the 250 ppb limit 4% of the time in room 1 and 8% in room 2, likely due to human activity. Higher baseline VOC levels outside the heating season suggest that open windows may increase exposure to outdoor pollutants, perhaps from nearby roads.

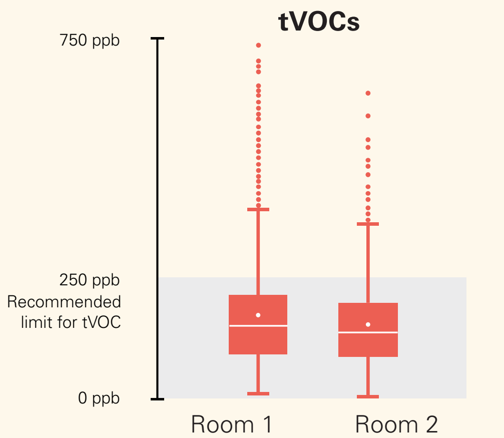
Internal condition benchmarking

Data represented for all measured hours across the monitoring period in 2022-23. The methodology section of this report gives further detail on recommended range evidence basis for each category.









User experience overview

There are significant limitations to our findings here, as only one resident agreed to participate in the quality of life component of the study. This outcome cannot be seen as a representative viewpoint in that regard, and more participants would have helped to give more certainty as to how commonplace the views shared are.

The resident described their home life like 'living on a constant holiday'. The survey captured a positive impact on health and wellbeing as the resident felt 'more calm and content'.

The occupant was made to feel more relaxed/ comfortable, creative, inspired, content and healthy/energised.

Compared to other buildings I've lived in, the timber features of this building make me feel more...

✓
Relaxed/comfortable
Creative
Inspired
Content
Healthy/energised

✗
Productive
Focused

As there was only one respondent, a bar chart is not suitable for representing findings to this question.

What do you like about this building?

"Love the way light moves around the building, and the beautiful patterns the sunlight makes against the wood."

"The wood interior is relaxing, calming and transportive - it's like living on a constant holiday. Coming home feels like an escape into a retreat. Our well-being and quality of life has risen so much since moving here."

The resident spoke most about the wood in their response:

User experience survey results

Category	Findings
Satisfaction	The occupant felt satisfied about the timber features and the building in general.
Meeting user needs	The occupant now notices timber features in other buildings more. They feel a sense of pride in the timber-designed nature of the building and have spoken a lot with others about it.
Perceived impact on health and wellbeing	The occupant has reported strong improvements to wellbeing and quality of life.
Comfort and indoor air quality	The occupant feels 'very positive' about the air quality in the building. Temperature is comfortable in winter but perceived by the occupant as slightly too warm in summer.
Sound	Of other occupants in the building, the occupant is fairly aware, but not very aware of noise outside.
Lighting	Very satisfied with the amount of daylight in the building.
Perceived control	The occupant feels it is easy to control how hot or cold the building is. The resident does feel they cannot make changes easily to the building. Unclear if this is due to timber material itself or other design features.
Utility costs	The occupant rated the utility costs as 5/7.

Figure 60. Top floor apartment living and dining area

Figure 61. Top floor apartment kitchen

Figure 62. Park block top floor apartment

Discussion

Homes are perhaps the most impactful typology out of all those we studied, due to the typology's contribution to carbon emissions and quality of life. Residential buildings are the source of nearly half of the UK's built environment greenhouse gas emissions. We spend a considerable part of our indoor lives at home - over 90% of our time - so homes have a significant impact on our quality of life. However, there is a 'perceived lack of quality of new-build housing' in UK housing delivery. Timber is also underutilised in housing delivery with just 9% of English homes built in timber frame, compared to 92% of new builds in Scotland. Mass timber likely represents an even smaller proportion of housing construction systems, though we lack data on this. Here then, at Rye Apartments, we see an **uncommon output of high quality, mass timber housing**, and this is also arising from an **unusual model of architect-as-contractor-developer.**

There are many CLT housing schemes that we reviewed in wanting to pursue a mass timber housing scheme, however Rye Apartments was one of very few that felt appropriate to study following Grenfell-related regulation changes and in consideration of what densities mass timber is most suitable for in terms of material efficiency. At three and four storeys, this building is **aligned to the scale of mass timber development that is possible to be constructed in the UK following the Building Safety Act**. We ruled out studying detached houses of one to two storeys as this would not be the most efficient use of the material structural capacity and density of resource, nor a sustainable scale of development.

The residential typology has well-established embodied and whole life carbon benchmarks, with the Rye Apartment buildings' embodied carbon impacts sitting comfortably within the **embodied carbon LETI 2030 design targets and the RIBA 2030 Climate Challenge** despite being designed before these targets were conceived of. It performs reasonably well on energy use intensity too, suggesting mass timber offers genuine potential to support low whole life carbon in this scale of housing development. Further enhancements in future schemes of this scale could be made in utilising biobased insulation and in potentially aligning design to Passivhaus.

Undertaking the quality of life component of in-person surveying was not as successful as we'd have liked, with only one household of the ten willing to engage on this study component. The feedback we did receive from this resident was very positive indeed, stating that their 'wellbeing and quality of life has improved so much since living here'. This suggests that **mass timber in home settings has potential to support enhanced quality of life**, but much more data will be needed to build a stronger evidence base, with **more and diverse case studies needed**. For improving uptake on internal condition monitoring, in-building monitors present a solution with minimal impact on residents in the future. For surveying, options for increasing engagement could include using rewards (e.g. a prize draw) for those taking part, although should be developed to be mindful of biases potentially arising here.

This case study is worth considering in relation to the 'New Model Building (NMB).' A key difference with the NMB approach and Rye Apartments is that the mass timber system of the NMB is required to be encapsulated for fire risk mitigation. This would offer a very different interior environment as compared to Rye Apartments, where much of the feedback has been in relation to the expression of the timber as a visual finish. Encapsulation of the mass timber structure would add non-biobased resource use in linings and an associated carbon impact. It may be that with encapsulated timber, there are still quality of life benefits that are less obvious (e.g. in internal environment comfort), so this would be good to study. In encapsulated timber buildings we would encourage using wider biophilic design moves where natural materials cannot be expressed, and trying to identify a **'goldilocks' spot between quality of life and fire safety**.

The **high quality of housing** offered by Rye Apartments is far beyond what is typical for housing construction in the UK. The homes were sold at above the average price in the area. Estate agents Modern House described that the building has 'a sincere focus on sustainability and low-impact construction permeates the design'. There is limited evidence for how much perceived sustainability or biophilic design elements contribute to housing value in the UK market.

Key takeaways

- This case study shows the **potential of mass timber homes to support quality of life of residents and to support decarbonisation efforts.** More case studies will be needed to build a compelling evidence base.
- The case study also highlights the **practical challenges of undertaking POE work in residential settings**. **Minimising frictions of POE work on the general public** will be critical in building support for wider application of these sorts of studies.

To be explored further

- We feel that wider research is warranted to understand how mass timber may provide a solution to decarbonisation and improved quality of life **through more residential case studies** at **a range of scales and densities.**
- Understanding **any uplifts to market value** from sustainability and biophilia in the residential market as compared to 'business as usual.'
- Identifying a **'goldilocks' spot for reducing fire risk and supporting quality of life** in future residential schemes would be beneficial - to avoid losing possible benefits of biophilic design.

Figure 63. Main entrance to school

Figure 64. Sports hall with visible mass timber structure as finishes

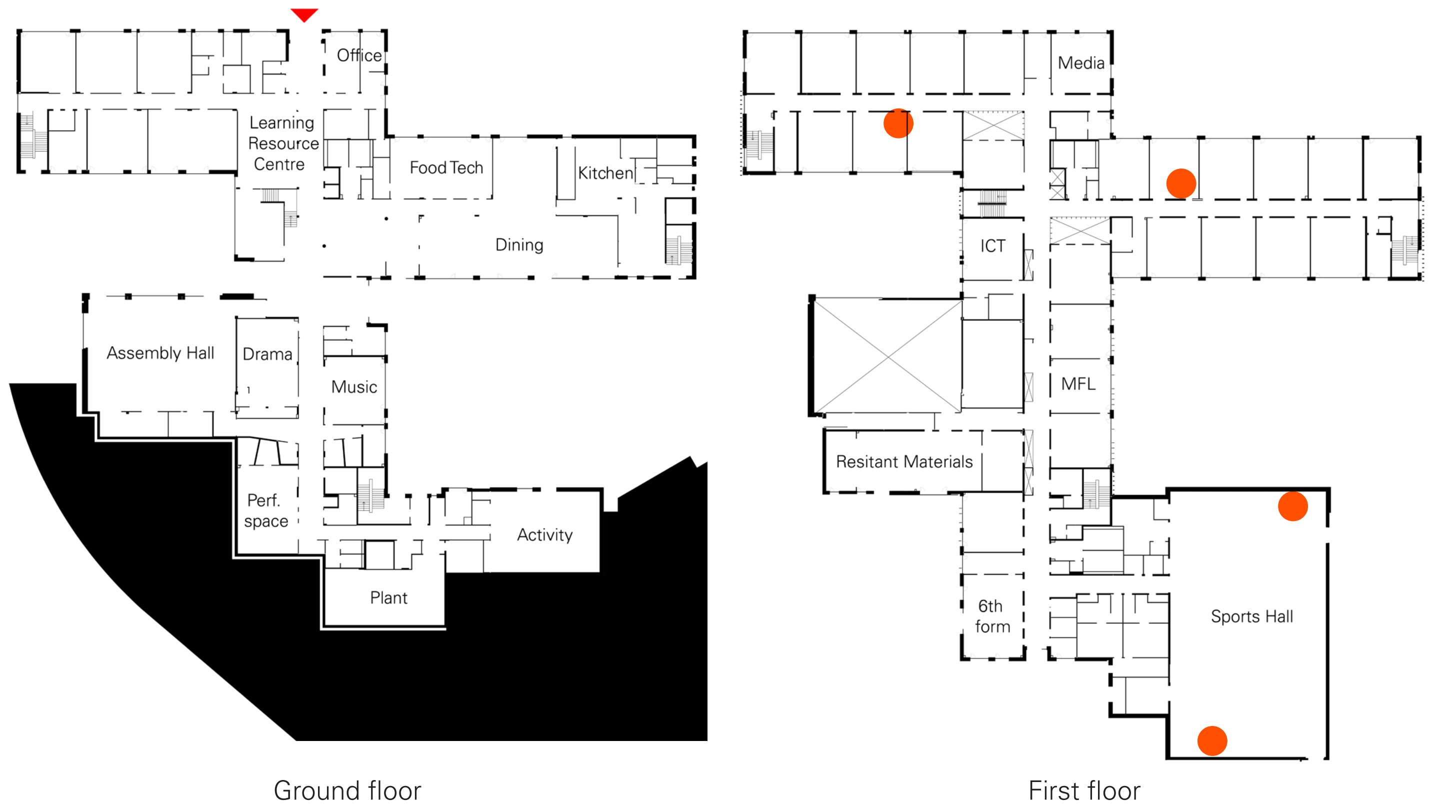
Sutton Harris Academy

Project Information	
Building type	Secondary School
Location	Sutton, London
Date completed	2019
Gross internal area	10,625 m²
Mass timber application	CLT/GLT corridor walls, some external walls, floors (first, second, third floors), and roof
Architect	Archiype
Structural engineer	Price & Myers
M&E	BDP
Main contractor	Willmott Dixon

Sutton Harris Academy is the UK's first Passivhaus secondary school. Located as part of the London Cancer Hub and adjacent to Royal Marsden Hospital, the school places a focus on sciences, aiming to 'inspire scientists of the future'. The six form of entry school is four storeys, with the assembly hall, dining hall, music & drama spaces, learning resource centre, ICT and offices on the ground floor. Maths, English and language classrooms are on level one, along with the large sports hall. Level two hosts further classrooms and art rooms and on the top floor are well-equipped science laboratories.

The ground floor is predominantly concrete in structure, while upper levels are CLT. There is significant exposed CLT internally including in class rooms and the sports hall. There are additional timber finishes including cladding and timber framed windows. Natural daylight and a relationship to the trees outside is established through the layout to ensure all classrooms have a connection with the outdoors.

High levels of insulation and airtightness reduce energy demand in winter, with additional heating from domestic-sized gas boilers. Summer comfort is maintained with night-time cooling and mixed-mode ventilation, demand controlled through MVHR.



Key

● Position of internal condition monitors (two additional monitors on second floor not shown)

SCALE: 1:1000 0 5 10 25 50 100m

Whole Life Carbon

Overview

The school designers had substantial building inventory data, having undertaken life-cycle assessments during the design process. The site condition inferred a need for a retaining wall condition in some areas (see ground floor plan), so the same system applied on a flatter site would see a lower carbon impact. Concrete constitutes the greatest proportion of A1-5 impacts, followed by mass timber elements, with almost half of those impacts matched with sequestration in the mass timber structure.

As the UK's first Passivhaus secondary school, the building targeted very low consumption of energy and water within life cycle module B6 and B7. End-of-life consumption is based on scenarios put forward from specific and generic EPDs.

Whole life carbon benchmarking

Benchmarks for school buildings have been positioned by LETI, RIBA and the pilot Net Zero Carbon Building Standard (NZCBS). As such, targets/limits are well-established in this typology. The building performs impressively against all the EUI limits/targets, showing how Passivhaus can provide a solution for meeting EUI targets with today's knowledge and technology, and perhaps these limits could be reduced further. The role of mass timber in this energy performance is less clear to determine. The embodied carbon impact is also performing well as compared to RIBA 2025 and LETI benchmarks. The building is effectively in line with RIBA 2025 given only a <1% exceedance. The NZCBS limit is overshot by 39%.

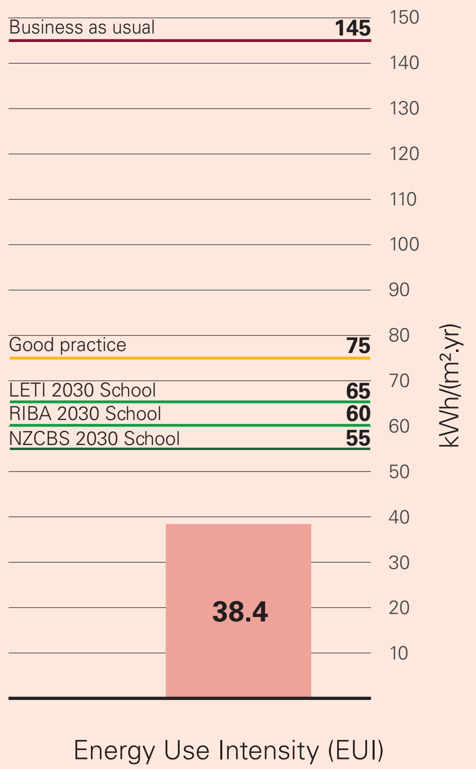
Life cycle assessment results

Life cycle stage	tCO_2e	$kgCO_2e/m^2$
Product stage (A1-A3)	3,557	335
Construction process (A4-5)	1,987	187
Upfront embodied carbon* (A1-5)	**5,544**	**522**
Upfront biogenic carbon (A1-5)	**-2733**	**-257**
Replacement (B4)	1,118	105
End-of-life (C1-4)	2,985	281
Embodied carbon (A-C excluding B6 & 7)	**6,914**	**651**
Energy use (B6) (decarbonised**)	3,230	304
Water use (B7)	15	1.4
Total WLC (A-C)	**10,159**	**956**
Benefits and loads beyond system boundary (D)	-1,038	-98

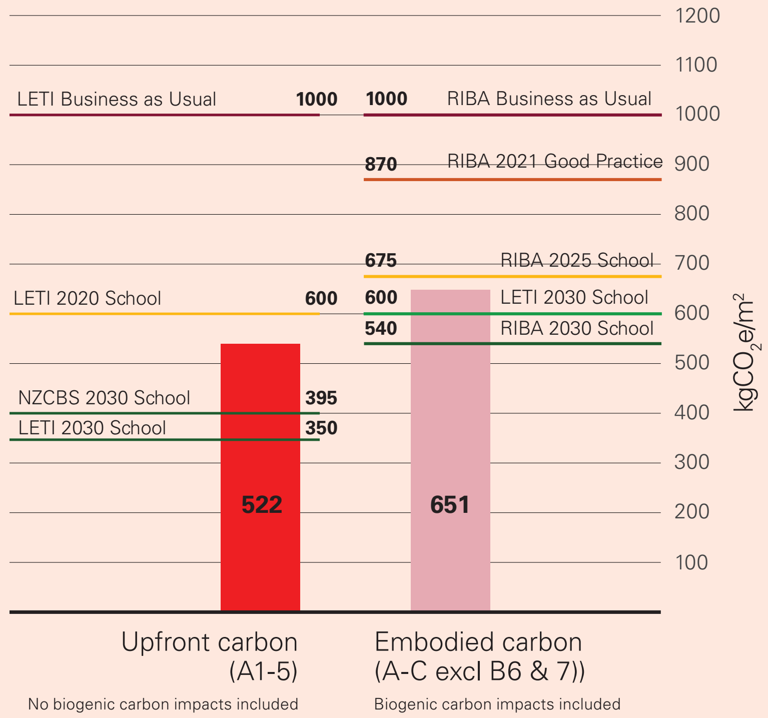
* upfront biogenic carbon is not incorporated in Upfront Embodied Carbon. Sequestered carbon is only accounted for (ie deducted) in Embodied Carbon across A-C modules in line with best practice.

** we have adopted a decarbonised grid scenario for the Energy Use prediction. Refer to Methodology for full explanation.

Energy Use Intensity (EUI)

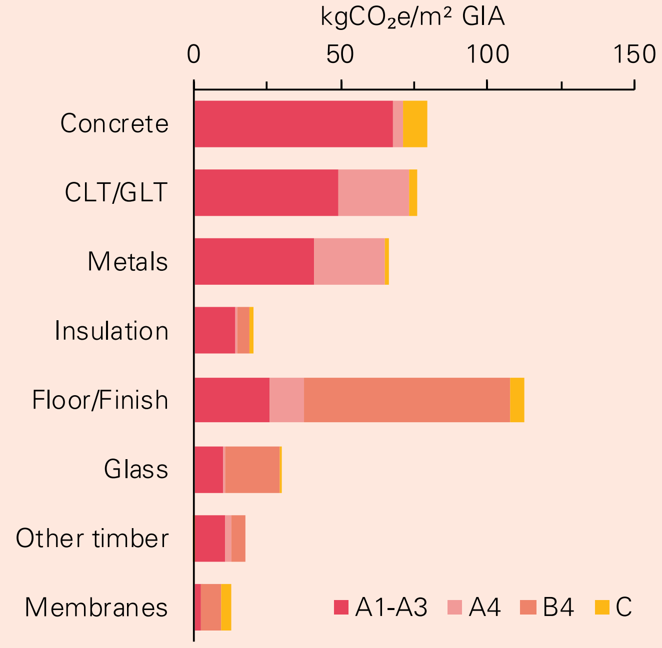


Embodied Carbon



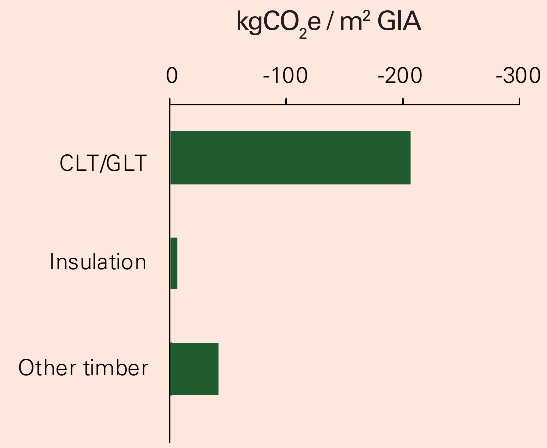
Embodied Carbon by material

We see here that CLT/GLT is comparable in impacts over the whole life to the concrete elements in the building. Floors and finishes contribute a significant proportion, owing to replacements over the whole life assumed. Membranes represent a bigger element in this building than others, likely in part due to the Passivhaus performance, however these should be considered in terms of whole life performance contribution to the impressive low EUI as benchmarked (see left).



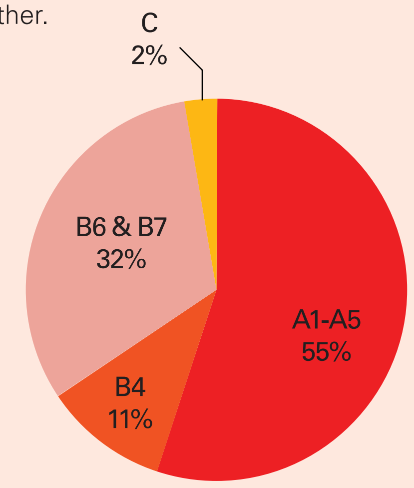
Upfront biogenic carbon by material

The majority of sequestration is within the CLT/GLT structure, although other timber in insulation and other elements contribute to a lesser extent. Opportunities to enhance the biobased sequestration potential in non-structural elements could include the facade.



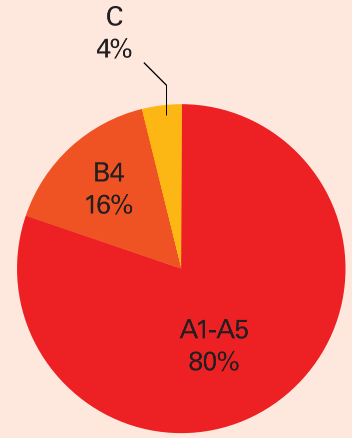
Whole life carbon (A-C)

Here the effects of sequestration are incorporated (i.e. the carbon stored in biobased products is deducted).
NB: The carbon pie charts are shown relative in scale to one another.



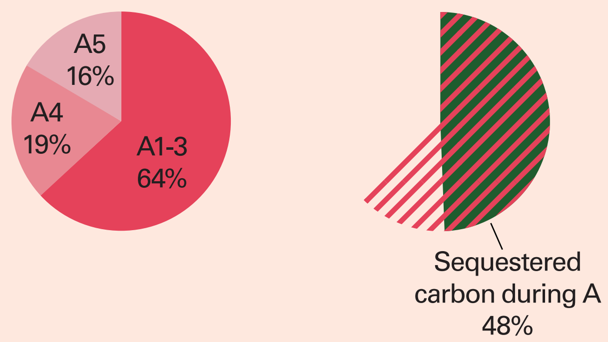
Embodied Carbon (A-C excl B6 & B7)

Here the effects of sequestration are incorporated. This is a typical scope used when benchmarking, with EUI typically benchmarked separately.



Upfront embodied carbon (A1-5)

When reporting upfront embodied carbon alone, the effects of sequestration cannot be incorporated. Shown below are the scale of sequestration impacts as part of A1-3 as a point of additional information. Nearly half the total A1-3 impacts are sequestered in the structure.

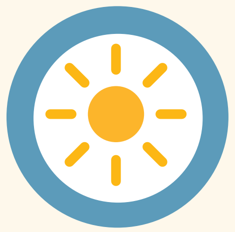


Quality of Life

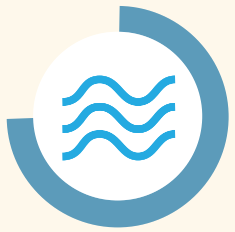
Internal condition monitoring overview

This was the largest building in the study with a lot of different spaces to be monitored. The school was in the process of a phased increasing intake while studied. We monitored a sample of spaces based on occupation at the time - four classrooms from a range of positions and two devices within the sports hall. With challenges in accessing the monitoring devices for syncing data, only 50% of the internal environment monitors returned consistent year-round data.

As a Passivhaus building, there are distinct characteristics as to how the building fabric and systems perform in use compared to 'business as usual' schools. This includes enhanced airtightness in the building fabric and use of active and passive systems. Monitored classrooms and sports facilities remain largely within comfortable ranges for temperature, humidity, VOCs and CO_2. More detailed study on comfort is encouraged as the school intake reaches the building's maximum occupancy.



100% of occupants were satisfied with levels of daylighting

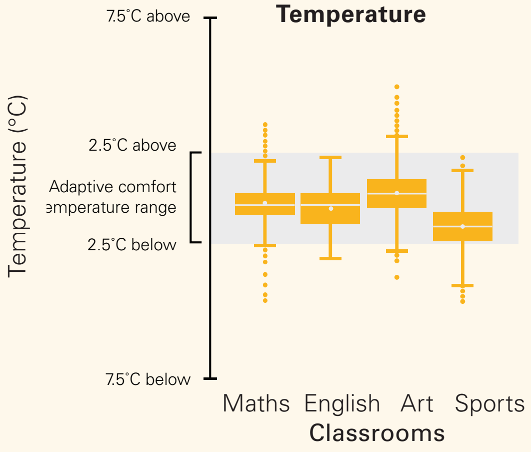


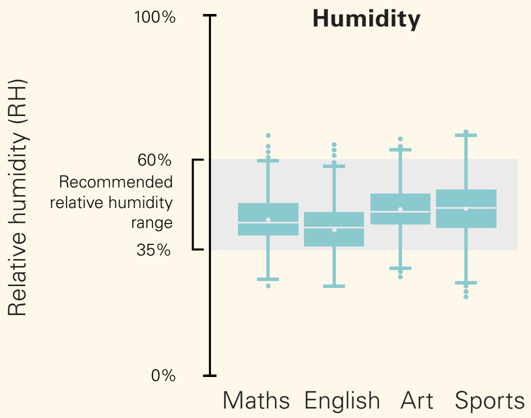
75% of occupants felt positive about the air quality

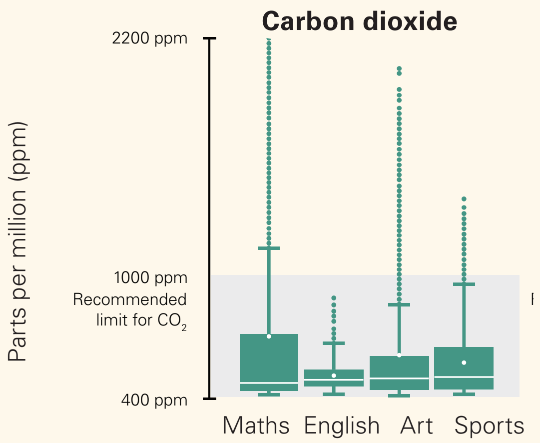
Internal condition monitor results

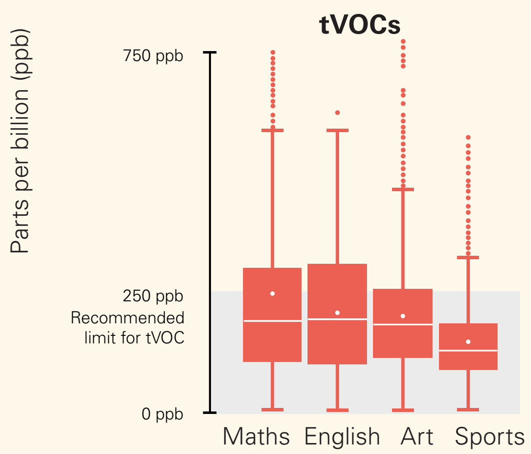
Category	Findings
Internal Temp.	Indoor temperature is generally well controlled. Classroom 4 tends to overheat slightly during occupancy (above 26°for about 7.7% of the time), likely due to high occupancy though further analysis may be useful. But for the most part, despite heatwaves or very low outdoor temperatures, comfort levels are well maintained year-round.
Relative humidity	Relative humidity is well controlled and mostly within the recommended ranges.
Air Quality	Ventilation performance was generally good, with median CO_2 levels within recommended levels. Classrooms 1 and 4 faced challenges during times of peak occupancy, but systems cleared the air effectively when unoccupied. Classroom 3 and the sports hall maintained excellent air quality, with only occasional CO_2 spikes out of normal school opening times. Total VOC levels are on the higher end of the recommended range, especially in the sports hall, with all spaces frequently exceeding 250 ppb for periods of time. With this said, VOC levels have been found in limited studies in other schools to have reached much higher levels than recommended levels, so this performance is still a reasonable improvement on 'business as usual'. VOC levels tend to drop during the day (6:30 am to 6:30 pm) but accumulate overnight, suggesting off-gassing from materials like construction items, furniture, or cleaning products may be present. Further research is encouraged to analyse further any of the mass timber elements' role in this if any. Although pollutants are typically cleared before occupancy, classrooms 1 and 4 have slightly elevated levels during occupancy, with 17% and 27% of hours above 250 ppb, likely due to human activity, which is less of concern.

Internal condition benchmarking









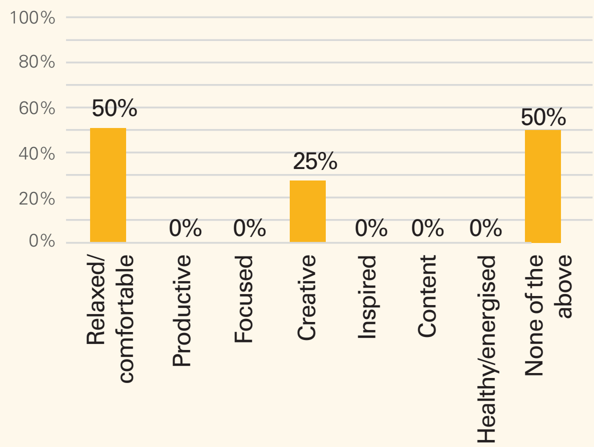
User experience overview

Despite the research team's efforts in engagement, we did not receive many survey responses - only four respondents. This should therefore not be seen as a representative sample. The findings are a starting point for understanding how mass timber influences quality of life in education settings, further studies would be encouraged. All the respondents 'felt positive about the `timber/ wood features' and 'satisfied with the amount of natural daylight'. Most of the respondents to the questionnaire felt that 'the materials in the school reminded them of the natural world'.

75% felt the materials in the building reminded them of the natural world

50% of occupants were made to feel more relaxed and/or comfortable by timber features

Compared to other schools or similar buildings, the timber features of this building make me feel more...



What do you like about this building?

"I like how the school is mainly wood and I like how the copper blends in with the wood."

"It looks bare* nice"

"It's quite nice and blends into the environment"

"I like how minimalist it is"

*Slang term meaning: very/a lot

Wood features quite strongly in the responses to this question:

User experience survey results

Category	Findings
Satisfaction	100% of respondents feel positive about the timber/wood features. More than half of respondents feel more focused as a result of the wooden materials and furnishings.
Meeting user needs	Occupants rarely speak about the wood/timber design of the school with others, but 75% of respondents are reminded of the natural world by the materials in the building.
Perceived impact on health and wellbeing	Respondents are either unsure about health benefits from timber design or agree that they are improved. Not many (25%) are aware of the health and environment benefits linked to the school's design, though one respondent highlighted energy efficiency.
Comfort and indoor air quality	All responding occupants feel either positive (75%) or neutral about indoor air quality. 75% feel it is too warm in summer, with 100% feeling slightly too cold or uncomfortably cold in winter. This suggests the BMS could be reviewed alongside considering uniform recommendations for different seasons to allow individuals to adjust comfort.
Lighting	100% of respondents are satisfied with the amount of natural daylight overall in the rooms in the school. Many studies have shown a connection between exposure to natural light and higher productivity levels in schools.
Perceived control	Temperature is monitored and controls by a central BMS, which one respondent queried, desiring more manual control.


Figure 65. An example of the exposed mass timber in classrooms

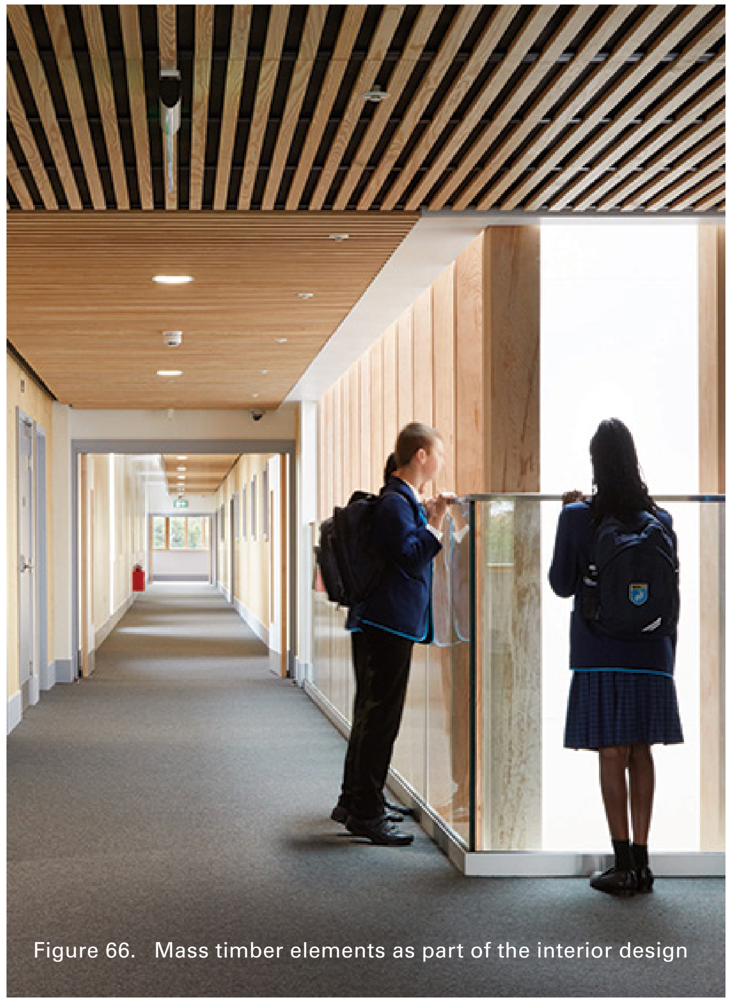


Figure 66. Mass timber elements as part of the interior design

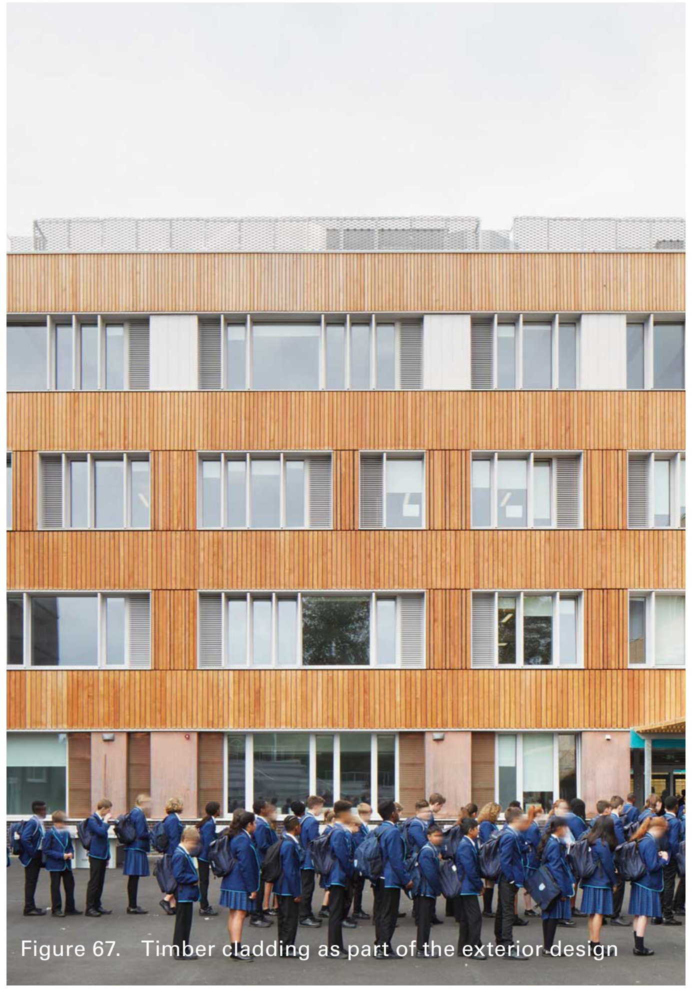


Figure 67. Timber cladding as part of the exterior design

Discussion

Extensive research has shown **education settings affect academic outcomes and the emotional wellbeing** of students and staff, with interiors particularly impactful. Of the limited research into the positive impacts of timber interiors, prominent examples include studies in school environments, such as "School without Stress" which found students learning in timber classrooms had lower heart rates than those in standard classrooms. We were interested at Harris Academy to explore how the interior expression of mass timber elements would influence the quality of life of students and staff working there, together with the wider sustainable design strategies.

This was one of the more challenging case studies to conduct in-building research activities for owing to the typology. While we developed a project-specific **safeguarding** strategy, the school of course has its own safeguarding controls and security. This added complexity to visiting as compared to our other case study buildings and was under-appreciated at the outset by the research team as a factor. Unfortunately, as we were not able to visit monitoring devices at the optimal frequency, there were stretches of time where our internal condition data was lost. We also did not have a statistically representative response to the survey. The quality of life component of the study could be improved in future studies with improvements to our approach to engagement - for instance in using continually-connected monitoring devices that would require no interim visits.

As a **Passivhaus certified building**, there is a strong design focus on airtightness and thermal performance to limit operational energy consumption. Passivhaus is a comfort standard and wider research indicates this will produce a healthier school environment. Beyond the strong operational savings we expected, embodied carbon emissions are well below those of a 'building as usual' school, in line with LETI 2025 Embodied Carbon targets (<1% above the recommendation). Of the occupants we surveyed, we found an appreciation of the resulting qualities of light and air, feel an increased focus and sense a greater awareness of the natural world. Internal condition monitors have shown that for a majority of the time, measured aspects are within recommended levels. This is a significant finding, in contrast to 'business as usual' school construction.

There is widespread lack of data around education buildings' performance. In May 2016, the RIBA set out in its 'Better Spaces for Learning' report a need for 'systematic Post Occupancy Evaluations', however from our experience in POEs still being outside the norm there is still a need for this to be addressed. Following the recent RAAC 'concrete crisis' in 235 UK schools, there is a fresh opportunity to re-energise this effort. We **support the proposal to undertake more widespread POEs in schools** to understand how upgrading the school estates with more mass timber systems can support carbon reductions as part of a wider retrofit strategy, with carbon benefits coupled with improved quality of life and performance for students and staff alike. Having funding made available is imperative to any wider rollout of POEs, to provide support staff and resources for study implementation, as teachers are already currently overstretched in the UK. There is a need to review evaluation approaches, with opportunity for the BS EN 40101 to have **typology-specific guidance for undertaking evaluations**. For instance, surveying children and vulnerable persons is underdeveloped in the standard, as is age-appropriate language guidance. Should also be aligned with/used to inform DfE BPE guidance.

The **UK government is exploring widening use of mass timber in school** construction, with 'GenZero' a pipeline of projects in progress, with a prototype of homegrown CLT exhibited at the BE-ST COP26 event in Scotland. Given the prevalence of poor-quality portacabin school spaces in the UK, there is a ready need for rapid, high quality construction alternatives and mass timber does offer a potential solution. The **complementary nature of Passivhaus with mass timber systems** is relatively underexplored, however it is possible that the two are complementary, with enhanced airtightness supported by prefabricated mass timber systems.

This is of course all connected to how important children are in enacting a sustainable future society. '**Children and youth are the most impacted by today's global environmental crisis** and are the most threatened by our current trajectory'. Educational settings can support children to be prepared for the world they inherit from us, and it is of paramount importance that their buildings are of the very best sustainability credentials supporting quality of life with this in mind.

Key takeaways

- This case study illustrates how mass timber combined with Passivhaus certification can offer a **low whole life carbon solution, while supporting healthy internal environments**.
- It is **challenging to undertake POE in education** settings in the present circumstances in the UK. More work is needed to develop appropriate methods that are scalable and pragmatic.
- The students we had feedback from feel positive about the timber/wood features, with a **sense of connection to the natural world supported.**

To be explored further

- There should be **joined-up thinking in a nationwide rollout of funded POEs** in schools as cost-saving and fact-finding exercises.
- **Affordable continually-connected monitoring solutions** could be explored further via a market-review of monitoring devices. New products may be required to address a market gap.
- We would recommend **streamlining expectations for POEs in education settings** to the most critical, impactful elements on limited visits. Can a light POE be done in just one day?

	ABBEY WOOD STATION	CAMBRIDGE CENTRAL MOSQUE	6 ORSMAN ROAD	PECKHAM RYE APARTMENTS	SUTTON HARRIS ACADEMY
					
	INFRASTRUCTURE	WORSHIP	COMMERCIAL	RESIDENTIAL	EDUCATION
WHOLE LIFE CARBON					
Upfront carbon (A1-5) Not deducting biogenic carbon	1,977 kgCO2e/m² *no benchmarks*	584 kgCO2e/m² *34% beyond NZCBS 2030 Worship limit*	376 kgCO2e/m² *32% below NZCBS 2030 Office target*	398 kgCO2e/m² *20% below LETI 2020 residential target*	522 kgCO2e/m² *12% below LETI 2020 school target*
Embodied carbon (A-C excl B6 & B7) Including deduction of biogenic carbon	4.9 tCO2e/m² *no benchmarks*	717 $kgCO_2e/m^2$ *no benchmarks*	605 kgCO2e/m² *Below LETI, RIBA and NZCBS 2030 targets/limits*	1,031 kgCO2e/m² *Below LETI, RIBA and NZCBS 2030 targets/limits*	956 kgCO2e/m² *~ RIBA 2025 target met*
Energy Use Intensity	480 kWh/(m². yr) *no benchmarks*	178.4 kWh/(m². yr) *no benchmarks*	94.2 kWh/(m². y) *28% below 'business as usual'*	68.8 kWh/(m². y) *~ half the EUI of 'business as usual'*	38.4 kWh/(m². y) *Below RIBA, LETI and NZCBS 2030 targets/limits*
Upfront biogenic carbon storage (A1-5)	315 tCO_2e	1071 tCO_2e	743 tCO_2e	296 tCO_2e	2733 tCO_2e
QUALITY OF LIFE					
Healthy building	All five buildings perform well against conservative benchmarks for internal conditions (humidity, temperature, carbon dioxide and tVOCs). The contribution of mass timber alone to this is hard to determine and warrants further investigation.				
User experiences	60% of occupants feel more relaxed and comfortable	90% of occupants feel more relaxed and comfortable	82% of occupants feel more relaxed and comfortable	Occupant feels a strong enhancement to quality of life	50% of occupants feel more relaxed and comfortable
Materials and nature	A strong consensus across all five buildings was that building users **feel reminded of the natural world by the materials.**				

Overall findings

We have applied a holistic method for whole life carbon and quality of life across five case study buildings. This limited cohort yields insights as to the decarbonisation and quality of life potential of mass timber buildings. The five buildings collectively perform well across all aspects assessed.

In terms of quality of life, **all buildings have been found through internal condition monitoring to provide healthy conditions**, benchmarked against conservative recommendations. As this sort of monitoring is not widespread, we cannot comment with certainty on how this relates to 'business as usual', but we would expect this to be a good performance level. There are no overly concerning findings, although each building's operations and management could be refined to further optimise their health supporting performance. We would assume from this finding that the buildings are supporting peoples' physical health, which is an important facet of quality of life. From the survey findings, which were variable in their uptake and representativeness across the five buildings, we have seen a strong alignment with people reporting 'good air quality' in their experience. This could suggest a potential for mass timber to support improved air quality as felt by humans, but this would need much more research.

Across all five buildings, **people have reported feeling more relaxed and comfortable in these buildings** as compared to other buildings. There is also a **strong sense of being reminded of the natural world by the materials in the buildings**. This suggests that the visual quality of leaving mass timber surfaces exposed is contributing to quality of life. Biophilic potential being fulfilled in supporting connection with nature. This is an important finding, as connection with nature is known to be critical in ensuring that people have quality of life, but also in driving a wider paradigm shift towards the restoration and regeneration of systems on our planet to address the climate and biodiversity crises. The buildings assessed represent key parts of peoples' everyday lives - places we travel through, worship in, work in, live/sleep in and where our children go to school. Repeated encounters with natural materials across all these building environments would likely have a multiplication effect. We are conscious that in the UK, encapsulation of timber structures is becoming increasingly necessary to address fire risk. We would like these findings to offer some perspective on the valuable role exposed mass timber can play, and to encourage industry stakeholders to address fire safety without limiting this significant quality of life potential.

Embodied carbon performance is a strong point, as when including biogenic carbon storage, the buildings perform very well against industry benchmarks (where these exist). For upfront carbon, we still see good performance against benchmarks, even though biogenic carbon is not incorporated. This is important, as it means that the other carbon impacts of mass timber (e.g. 'substitution' and 'knock on efficiencies') offer **decarbonisation impact beyond sequestration and storage.** As upfront emissions occur *now*, this suggests that **mass timber offers a means to reduce carbon today, even without accounting for the biogenic storage potential**. These benchmarks were conceived after the buildings were designed, so even being close to attainment is impressive. The **energy use intensity of the buildings also outperforms business as usual**, while Sutton Harris Academy shows that there is potential where applying Passivhaus standards to meet 2030 targets today.

Across our five case studies there is **significant biogenic carbon storage**, with 5,158tCO_2e upfront carbon stored, predominantly in the mass timber structures. For scale, this equates to the carbon impact of building 161 'business as usual' homes[99], or 396 years of an average Brit's annual emissions[100], or flying from London to Hong Kong and back 1478 times[101]. It also represents the carbon stored in the trees of 17.7 hectares of UK woodland[102]. **The mass timber case studies store three times more carbon than the equivalent area of UK woodland.**[103]. There is still opportunity to enhance this biogenic storage potential in future buildings, with insulation, cladding and finishes all opportunities for further, if shorter lived, carbon storage. Increasing volumes of insulation can also support reduced EUI, a win-win. We hope that this biogenic carbon remains in storage for a long time to maximise the impact these buildings have. As these buildings are well-loved and supporting quality of life, there is a greater certainty that they will remain looked after and well-used for a long time to come. This could be the greatest synergy between carbon and quality of life.

As we have only assessed five buildings, these findings should be seen as indicative. To make an even more robust case for mass timber's role in terms of decarbonisation and quality of life potential **we need far more data, far more case studies**, conducting comparable studies. In time, we hope that this dataset will grow. We are **confident however that we have started to evidence the positive impact mass timber can have for decarbonisation and for quality of life.**

Conclusions

4

Overview

This report has explored how mass timber buildings have the potential to generate positive impacts for people and planet. We have outlined an approach for appraising these impacts by standardising a methodology, applied to five case study mass timber buildings. The findings from this cohort suggest mass timber positive impacts on both quality of life and whole life carbon.

We write this report at a time where the situation is looking more positive for mass timber to be scaled up in the UK, with the ‘Mass Timber Insurance Playbook’[104] and ‘New Model Building’[105] addressing key industry barriers to utilisation of mass timber systems, including in residential schemes. We hope that moving forward there will be greater scrutiny of the efficiency of mass timber utilisation and the role that exposed mass timber offers in enhancing quality of life. Balancing this potential alongside mitigating fire risk is important and the potential benefits for quality of life for natural materials to be expressed internally should not be underestimated.

By the time you read this report, it will most likely be 2025 - the midway point for needing to reduce carbon emissions by 50% as compared to 2020 baseline. Urgent change is needed for us to protect nature and ourselves against the worst projected impacts of climate change and biodiversity loss. The WWF has stated chillingly that ‘it is no exaggeration to say that what happens in the next five years will determine the future of life on Earth’.[106] We have now had 29 COPs, and yet still we are so far from making the changes scientists say are needed to preserve life as we know it on this planet.

We need new narratives to support changemaking. Those advocating for timber in construction have had to overcome numerous negative communications and regulatory barriers, as already mentioned. Our desire to conduct this research project was in part to increase the positive evidence base for why mass timber can be so wonderful to build in as compared to and distinct from business as usual alternatives - for both people and planet. We wanted to ensure that the positives we claim timber to have really hold up under thorough scrutiny. For as David Attenborough has highlighted, the climate crisis is now a ‘communications challenge’. We cannot afford to greenwash our way out of this. With this context firmly in mind, we will now explore how the initial hypotheses statements and whether they have held up following the completion of the research activities.

> **‘The world is in trouble. Continents are on fire, gases are melting. Coral reefs are dying, fish are disappearing from our oceans – the list goes on and on… Saving our planet is now a communications challenge. We know what to do, we just need the will.’**
>
> David Attenborough, 2020[107]

Primary research hypotheses recap:

1. **Mass timber buildings offer the potential to support decarbonisation** and this can be evidenced through built case studies of a range of typologies as compared to industry benchmarks.
2. **Mass timber buildings contribute to quality of life** and this can be evidenced through quantitative and qualitative evaluation of peoples’ experiences in inhabiting/using mass timber buildings of a range of typologies.
3. **A methodology can be refined to assess both whole life carbon and quality of life** for existing mass timber buildings that can be repeated by others in the future.
4. **Mass timber supports generation of a holistic ‘whole life value’.** There are synergies to be found from applying this method between quality of life and decarbonisation potential of mass timber.

1. **Mass timber buildings offer the potential to support decarbonisation** and this can be evidenced through built case studies of a range of typologies as compared to industry benchmarks

Our finding is that the five mass timber case study buildings perform well against industry targets for whole life carbon. In particular, for upfront and embodied carbon. We feel that the hypothesis is met.

The case studies’ strong performance against upfront carbon benchmarks is particularly interesting. Biogenic carbon is not permitted to be incorporated (i.e. deducted) into the impact for upfront carbon. This means that mass timber’s other decarbonisation potential is shining through - such as generating multiplier effects (by being lighter structures and needing less foundations, by not requiring so much additional material internally). While performance in energy use is better than ‘business as usual’ across the cohort, there is room for improvement for their energy use intensity. As Sutton Harris Academy proves, mass timber can be highly compatible with Passivhaus standards to attain ultra-low energy performance. It is important to contextualise this good performance against industry benchmarks with remembering that all five buildings were all constructed by 2020. This is well before LETI / RIBA 2030 /Net Zero Carbon Building Standard targets were conceived. This underlines that mass timber is a tool for decarbonisation that can be implemented *today* to meet tomorrow’s targets.

No building from our case study cohort is purely mass timber and all rely to some extent on a hybrid system, e.g. all have concrete foundations. It is therefore paramount that even when designing a ‘mass timber building’ we consider enhancing the sustainability performance of *all* materials and elements. Zero carbon cannot be met without also tackling the hardest to abate material types. We should use mass timber responsibly - be mindful when designing buildings as ‘mass timber’ that we do not allow it to ‘offset’ continued use of high carbon and high finite resource energy/water consumption that is avoidable elsewhere in the building system. We need to continue to work as an industry to decarbonise all material supply chains. We should consider designing efficiently in timber to ensure we maximise the resource availability.

We have highlighted the importance of consistently applying whole life carbon methods. This is to ensure communication of carbon impacts is consistent and clear to a wider audience. We also believe more work is needed to refine carbon accounting practices to represent the likely whole life carbon impact arising from biogenic carbon, particularly at end-of-life.

2. **Mass timber buildings contribute to quality of life** and this can be evidenced through quantitative and qualitative evaluation of peoples’ experiences in inhabiting/using mass timber buildings of a range of typologies

Our finding is that the communities using the case study buildings overall self-report improved aspects of quality of life. They collectively report a sense of being reminded of the natural world by the materials. They also report feeling more relaxed/comfortable in these buildings compared to others. The buildings also represent healthy conditions as measured by internal condition monitors overall.

We know that mass timber construction currently represents a small portion of UK construction. While more research is needed to explore quite how much it does constitute, this means that relatively small numbers of the British public have had the experience of living, working and moving through mass timber buildings. Starting to understand therefore the possible impacts on quality of life is significant, as these lived experiences are not widespread and the implications of using buildings made of mass timber are currently a rarity.

There is growing evidence suggesting that, when incorporated into the design of a building as a natural and structural/building material, the biophilic properties of wood do result in enhanced physical and mental wellbeing. This study and its focus on the qualitative / user experience elements around how a person feels when interacting with a mass timber building, should be seen to complement the wider literature and work which is ultimately trying to make our spaces and places healthier and better for the environment.

A major methodological challenge for this material-focused POE, has been the ability to separate the impact of good design, generally, and the impact of the timber specifically without creating biased or leading questions, as one respondent put it: “I’m not sure if it’s the timber design or just the space”. We have identified a context of wider studies revealing the positive relationship between natural materials, timber in particular, and occupant quality of life. So it is recommended not to see the outcomes on this aspect of our study as fully conclusive yet, across such a small sample of buildings, but a contribution towards the growing pile of evidence revealing the wide spectrum of benefits mass timber buildings can have. As we continue to discuss appropriate standardisation of the POE approach, when combined with its accompanying whole life carbon report, this project has broadened the scope of their application and access to their opportunities and challenges. Understanding our buildings better is similar to the process of understanding ourselves better - it's a life's work and as time passes there is always more to discover. This project goes some way in contributing to this ongoing endeavour.

We have had to contend with the very practical realities of undertaking fieldwork-based research, taking us away from the comforts of our desks and the calculative analysis of whole life carbon alone, to actually visit the five buildings ourselves and to understand how they work in practice. Putting internal condition monitors in a prayer hall, a basketball court, a classroom, a snazzy office and someone's bedroom all create challenges in their own ways, as does asking people to invite them into their building and open up about their experiences with total strangers.

But speaking to strangers has been one of the most powerful parts of this study, with people sharing unexpectedly powerful accounts of their relationships to these buildings. We have seen in the Cambridge Mosque people travelling hundreds of miles to visit and pray in the building, having heard of how beautiful the experience is. Across the case studies we have heard residents and occupiers of the full range of buildings speaking with pride and adoration about the buildings they use day-to-day. We have seen that quantitative data recorded with the internal condition monitors tallies by and large with the qualitative experiences of occupants. This begs the question as to whether retrospectively placing devices and monitoring buildings is quite as effective as simply asking people about their own comfort levels. For others seeking to replicate the study with constrained timelines or budgets, we would encourage the surveying approach to be applied on all built buildings. We certainly don't believe it would be appropriate to monitor buildings in the absence of this human-led experiential information being captured in parallel.

We have met the requirements to describe this study as 'Preliminary BPE with investigative elements', with some areas of a 'Light' or 'Standard' BPE not quite met in this instance. We have shown that there are areas where BPEs could be improved to better consider quality of life in the round and to appraise carbon impacts of buildings in one combined method. There are also instances where perhaps the theoretical approach to undertaking this work doesn't marry with the cost and time available to undertake this work. With more time and funds we could have gone further with the Building Performance Evaluation, to look more deeply at the building fabric performance and we would encourage all the participating architects and building owners to consider the potential to undertake further BPE activities. However, we are satisfied that we have begun to understand the more holistic ways that mass timber buildings perform, and in the relatively new territory of how they influence quality of life.

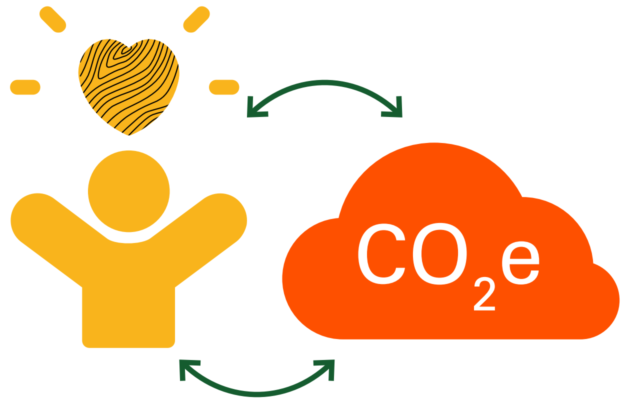
3. **A methodology can be refined to assess both whole life carbon and quality of life for existing mass timber buildings that can be repeated by others in the future**

We have demonstrated that it is possible to assess buildings in relation to their whole life carbon and quality of life in conjunction with one another. There are certain advantages to doing this sort of work all at once. We have shared our methodology so that others may replicate the study to build a larger dataset and evidence base.

Doing this sort of research requires communication with building occupiers and owners, and so streamlining requests for site access alongside requests for access to BMS data or utility bills can be a positive. However there is a risk of overburdening individuals who are not aware of the layers of information and frequency of site access required in undertaking this work.

This study has taken longer than was originally anticipated in large part due to the complexity of working with a fairly substantial range of stakeholders and the nature of doing in-person and in-building study activities beyond solely desk-based research work. The challenging nature of getting the in-person/in-building aspects complete does seem to have been fruitful enough to justify the undertaking. We would argue that part of this challenge can be attributed to the lack of normalisation of this sort of work in industry still at present. This is despite years of industry experts calling for change in this regard.

We hope that having thoroughly tested the methodology in full and shared details of the challenges experienced and how they were overcome, we will make it easier for others to replicate this work. We will be considering how to establish a data sharing platform or initiative to grow the dataset to cover a wider range of typologies and mass timber construction types.



4. **Mass timber supports generation of a holistic 'whole life value'.** There are synergies to be found from applying this method between quality of life and decarbonisation potential of mass timber.

We have observed synergies between the case for reducing carbon emissions and the need to support enhanced quality of life. The two elements of whole life carbon and quality of life are not necessarily obviously linked at first glance. You could of course study whole life carbon independently to quality of life, undertaking one piece of work years apart from the next. We would however argue that studying these two elements together provides more holistic understandings of how buildings perform and avoids potential unintended consequences that can arise when focusing upon a single issue.

We have seen strong synthesis between leaving mass timber systems exposed - without additional materials and being hidden behind plasterboard - as supporting quality of life. We know that this is a challenging finding, with the current status of insurers confidence in mass timber necessitating total encapsulation. But to do so unquestioningly is not ideal for carbon, nor for quality of life. We would encourage maintaining a preference towards exposed mass timber surfaces as far as possible, wherever it is safe to do so. We would encourage when it is not possible to leave mass timber exposed to then seek other opportunities for biophilic design to be incorporated in architectural designs. For instance, in specifying natural materials throughout interiors, facades and landscapes.

Furthermore, we would argue that a strong synthesis between quality of life and carbon is where we start to see how well-loved buildings are kept in use for longer than their design life (as relied upon for the embodied carbon analysis) and for the biogenic carbon to be held in storage for as long as possible. In our view, one of the best ways to extend carbon storage in the built environment is through designing and making places that people love, are proud of and that add to their quality of life. And so in evaluating both aspects together, we start to build confidence that this selection of case studies is unlikely to be deconstructed anytime soon, and more likely will be looked after throughout their design lives and beyond.

There is also the consideration that with a limited remaining carbon budget and with an urgent need to decarbonise, we simply cannot afford to be building architecture that does not provide an enhancement to quality of life. We must design for people *and* planet. As embodied and whole life carbon likely become regulated in the UK and beyond, we expect there to be a significant uplift in mass timber buildings. This opportunity should be harnessed to also increase quality of life.

Key challenges

A key challenge has been keeping the research focused to our core question around the impact of mass timber, without opening up enquiry to be a more exhaustive critique of the buildings in question or a wider set of questions.

You will have seen from our 'further exploration boxes' how much else there is space to delve further into - there is so much for the whole industry to engage with in future research investigations. It has been also challenging to extricate through the method the impacts of mass timber alone, as buildings are of course a composite of a huge array of design choices, materials and their circumstance of contexts.

It's been said time and time again by others, but now you will hear it from us one more time - building performance evaluations are not being conducted in industry at scale enough. This has been a barrier, as processes are not yet widely in place to support this sort of work, while technology is still being improved for conducting internal condition monitoring.

Another aspect which has been challenging, but rewarding, has been stakeholder engagement. Not all stakeholders have had previous knowledge and experience of some or even all the methodology and underlying concepts, so we have needed to take more time and care along the way to ensure everyone is giving 'informed consent' to participate and that they understand the purpose and objectives of this research and how it might be useful.

An unexpected outcome of this has been the extent to which we have upskilled and raised awareness of the interconnected concepts with the participants, including architects, building owners and occupants. More time was spent than expected in dialogue with this range of stakeholders and we have learnt a huge amount about communicating this subject matter and this sort of work to a range of audiences. Engaging together with the network of stakeholders was a real value of this project, as much as the method, data and findings were.

We believe that far more research needs to be undertaken into how buildings perform in use in a holistic sense, ideally using the same consistent industry best practice approaches to measuring whole life carbon and quality of life. We would like to see in future a much vaster dataset on the performance of mass timber. This would act as a better evidence base for advocating for mass timber. as a viable alternative to business as usual methods of construction, while also helping to drive quality in how mass timber is implemented for people and planet.

Areas for future study

Throughout this report we have highlighted areas of opportunity for future study. These include:

- Exploring case studies of mass timber buildings that are retrofit/adaptive reuse of existing buildings and/or examples where timber is fully encapsulated and there is no visual connection to the timber structure. We would hypothesise that the embodied carbon impact of retrofit/adaptive reuse schemes would perform very well, while the quality of life impact of encapsulated projects would not be tangible.

- It has not been possible in this research project to understand the full extent and proportion of mass timber construction as a part of the UK construction market. We would hypothesise that there is a fairly substantial component in some sectors (hospitality, residential pre-dating 2019, education), and less so in others (infrastructure, healthcare, commercial). We would suggest this research would be valuable to ensure that industry efforts are working to affect areas with most substantial potential for change.

- It has been an underlying assumption in this research study that all timber referenced is sustainably sourced and from responsibly managed woodland. This is an area that itself warrants further research. dRMM is currently working on a separate research project in collaboration with the BE-ST and Ecosystems Technologies looking at the role of Homegrown Timber and making harvested wood products from British wood supply towards this effect. We believe far more needs to be done to demonstrate the carbon story of timber in relation to the forest to the building.

- Sequestration is an area of much research and debate, as the current linear LCA methodology does not necessarily represent real-world performance of timber structures, which we know can far exceed the 60-year lifespan suggested and store carbon for much longer time horizons. TDUK have proposed end-of-life approach to fill data-gaps and improve upon generic approaches to end-of-life. We have in this paper followed current UK industry best practice, however we do want to lend our voice to the need to further understand and explore how reporting conventions may or may not support decarbonisation. Dynamic LCA approaches are being utilised elsewhere in Europe, for instance in France with the RE 2020 approach.

- We have focused on the quality of life of those using and working in these buildings today in-use. We see opportunity to explore the quality of life of the construction phase of mass timber buildings, to contribute to a healthier construction sector and for contributing to a more positive role of construction within urban places that are increasingly dense and with being a good neighbour outside the site boundary.

Closing thoughts

A useful lens to view this study is through time. Time is the crucial component to understanding the building life cycle, by returning to the past for the origin of materials, looking closely at their present configuration and projecting their future. Time is vital to gathering seasonal and diurnal data on indoor environments, and in recognising the changes to systems which follow their fluctuations.

Different definitions to time, i.e. calendars and schedules, are what shape the days, weeks and years of people that use the buildings, and how they interact with them. Such concepts of time are little discussed in architecture practice, which places an emphasis on the unchanging character of a structure designed to stand in the same form for 60-100 years, and which aligns with the objectives of a local authority, client or user at a specific point in time. We need to ensure we all undertake close examination of buildings and how they are used today, particularly in the face of disruptions in climate, technology and social order. For this, the whole sector must make time.

We see a fundamental tension existing between the urgency of addressing the climate crisis held in cognitive dissonance against the long-lasting, permanent nature of making architecture. ‘Low carbon’ is not aspirational enough. It is impossible to design architecture that is truly sustainable (or dare we dream, regenerative) without being fully considerate of the implications for quality of life. Indeed, of our case studies, there are moments of architectural flourish in how mass timber systems have been applied that most likely increase the carbon impact to some extent, however improve individuals’ quality of life such that these assets will be well loved and cared for. We believe that this will likely help to ensure these buildings will be storing carbon for far longer than current whole life carbon life cycle assessments will allow us to account for.

Mass timber is not enough on its own as a solution however, we should not overstate what can presently be achieved merely by substituting one structural system for another. Deeper, more holistic change is needed in a ‘whole life’ mindset. Mass timber shouldn’t be considered in isolation, but as part of a wider set of tools for decarbonisation and improving wellbeing. All of the case study buildings in this cohort involve the use of concrete, of steel, of glass. Can you name a building that does not need to use at least one of these finite resource-reliant, higher carbon materials today?

While reuse and restoration projects were not looked at in this case study cohort, we know that we ought to use less material to build buildings; to reuse existing assets wherever possible. We need to be more considerate of end-of-life scenarios in how we design all buildings, including mass timber ones, for how to ensure carbon storage continues and resources can be continued to be useful at their highest value. And we need to refine the methods by which we carbon account to incentivise long-term carbon storage further, also while improving accuracy of data in balance with ensuring widespread consistency in methodological adoption.

We hope that this research will go some way to helping others to conduct similar research, to build a more robust case for biobased materials. We would like to see dataset expanded to include more case studies, more mass timber systems, a wider range of biobased material types, more locations... and we hope that there will be appetite to support this mission beyond this report. We see a need to continue to build an evidence base to support positive narratives, while also using this analysis to help us to collectively strive for better application of best practice design strategies, to move towards a truly sustainable, regenerative built environment.

In the meantime, the glimpses of evidence coming from the five case study buildings feel like a powerful beginning in building the case for mass timber. We have seen how mass timber supports lower carbon construction today. We have seen how mass timber and biophilia can help people feel more connected to nature, to feel more relaxed and comfortable and to provide healthier internal environments. So let’s accelerate its use responsibly and efficiently, and in so doing support forestry practices to drive their standards up, becoming even more sustainable, biodiversity-supporting and ethical in the process.

Appendix

5

Abbreviated terms

ACAN Architects Climate Action Network
AD Architects Declare
AHEC American Hardwoods Export Council
ARB Architects Registration Board
AR6 Assessment Report 6
ASHRAE American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASBP The Alliance for Sustainable Building Products

BBN Built by Nature
BECD Built Environment Carbon Database
BEIS Business, Energy and Industrial Strategy
BE-ST Built Environment - Smarter Transformation
BMS Building Management System
BPE Building Performance Evaluation
BRUKL Building Regulations UK Part L
BRS Building Research Solutions
BS British Standard

CCC Climate Change Committee
CDM Construction (Design & Management)
CLST Cross Laminated Secondary Timber
CLT Cross-laminated Timber
CNC Computer Numerical Control
COP Conference of the Parties
CO2e Carbon dioxide equivalents
CCS Carbon Capture and Storage

DEFRA Department for Energy, Food and Rural Affairs
DfE Department for Education
DFMA+D Design for Manufacture, Assembly and Disassembly
DLT Dowel Laminated Timber

ENU Edinburgh Napier University
EoL End-of-life
EPD Environmental Product Declaration
EPC Energy Performance Certificate
ESAG Expert Stakeholder Advisory Group
ESO Electrical Systems Operator
EUI Energy Use Intensity

FES Future Electricity Scenarios
FF&E Fixtures, Fittings and Equipment
FU Functional Unit

GIA Gross Internal Area
GHG Greenhouse Gas
GLT Glue-laminated timber
GWP Global Warming Potential

IPCC Intergovernmental Panel on Climate Change

LCA Life Cycle Analysis
LCI Life Cycle Inventory
LCIA Life Cycle Impact Assessment
LETI Low Energy Transformation Initiative (formerly London Energy Transformation Initiative)
LSL Laminated Strand Lumber
LVL Laminated Veneer Lumber

M&E Mechanical and Electrical
MEP Mechanical Electrical and Plumbing
MMT Measuring Mass Timber (this research project)
MTRC Mass Timber Risk Consulting
MVHR Mechanical Ventilation Heat Recovery

NLT Nail Laminated Timber
NZCBS Net Zero Carbon Building Standard

PHPP Passivhaus Planning Package
ppm Parts per Million
PSL Parallel Strand Lumber
PVs Photovoltaic (panels)

QoLQuality of life
QoLF Quality of Life Foundation
QR Quick Response

RAAC Reinforced Autoclaved Aerated Concrete
RE202 Environmental Regulations 2020
RIBA Royal Institute of British Architects
RICS Royal Institute of Chartered Surveyors

STA Structural Timber Association

TDUK Timber Development United Kingdom
TiC Timber in Construction
TM54 Technical Memoranda 54
tVOCs total Volatile Organic Compounds

UCL University College London
UK United Kingdom
UKGBC United Kingdom Green Building Council

WLC Whole Life Carbon

Glossary

We have sought to use widely accepted or industry best practice derived definitions for key terms. This list is by no means exhaustive, we would recommend referring to our bibliography for reliable sources of industry-agreed terms.

Biogenic carbon 'Carbon removals associated with carbon sequestration into biomass, as well as any emissions associated with this sequestered carbon.'[108]

Biophilia 'The inherent human inclination to affiliate with natural systems and processes.'[109]

Biophillic design seeks to create good habitat for people as a biological organism in the modern built environment that advances people's health, fitness and wellbeing.'[110]

Building Performance Evaluation 'the term used to describe the gathering of quantitative and qualitative data that characterise the performance of a building [...] and the interpretation of these data to draw conclusions regarding specific performance attributes and the overall performance of the building.'[111]

Carbon emissions the aggregate process emissions of various gases that contribute to global greenhouse effect. This is recognised as a proxy measurement for climate change or global warming potential (GWP) and is measured in units of carbon dioxide equivalent (CO_2e). In this metric CO_2's GWP is used as the reference, representing one unit of CO_2e.

Carbon storage of that carbon which has been sequestered. The duration can be for varying timespans. Maximising long-life carbon storage helps to extend the period before any re-release of carbon dioxide back into the atmosphere for as long as possible, allowing us more time in the here and now to decarbonise other systems.

Embodied carbon 'The embodied carbon emissions of an asset are the total GHG emissions and removals associated with materials and construction processes, throughout the whole life cycle of an asset (modules A0–A5, B1–B5, C1–C4, with A0 assumed to be zero for buildings.'[112]

Energy use intensity the total amount of energy used in a building in a year divided by its floor area.

Environmental Product Declaration 'A document that clearly shows the environmental performance or impact of any product or material over its lifetime.'

Internal environment quality the measurable performance of a building against a range of conditions factors, combined with the user experience as derived from surveys and interviews.[113]

Life cycle inventory This is the total of recorded materials/products and quantities used to construct the building. This forms the basis of a whole life carbon assessment.

Mass timber refers to engineered wood products that are laminated from smaller boards or lamella into larger structural components.

Occupant satisfaction 'the degree to which occupants prefer or dislike different aspects of internal environmental quality. It can only be measured through surveys and interviews.' [114]

Regenerative design an approach in which human systems are designed to co-exist and co-evolve with natural systems over time.[115]

Sequestration This is the process of capturing carbon dioxide occuring as a result of a range of chemical and physical processes, both natural and human-induced.

Sustainably sourced timber 'must be grown and harvested in responsibly managed forests, which are continually replenished and regenerated. [...] the needs of wildlife, environment and local community' are balanced.

Timber refers to the wood of trees that can or will be used for building materials. Timber and wood are often used interchangeably.

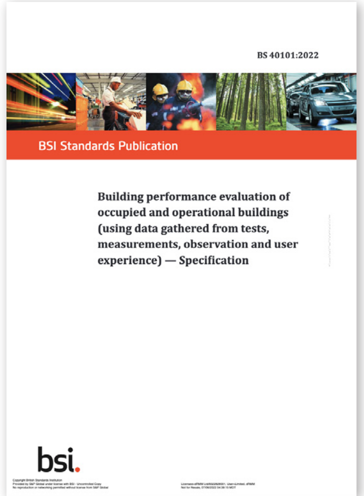
Quality of life The level to which individuals may feel their lives to be happy, active, sociable, interesting and meaningful.

Whole Life Carbon emissions are the sum total of all asset related GHG emissions and removals, both operational and embodied over the life cycle of an asset including its disposal.

Recommended reading

Architects Declare. *Practice Guide.* Architects Declare, 2021

Architects Declare. *Regenerative Design Primer.* Architects Declare, 2024



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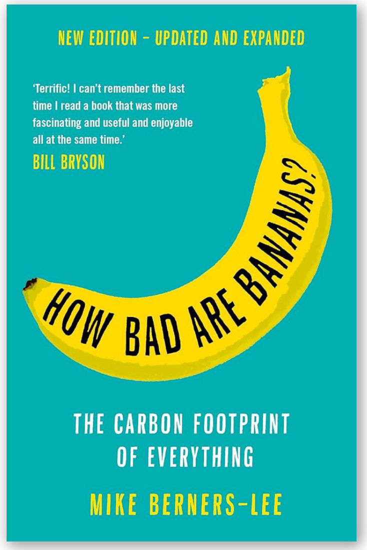

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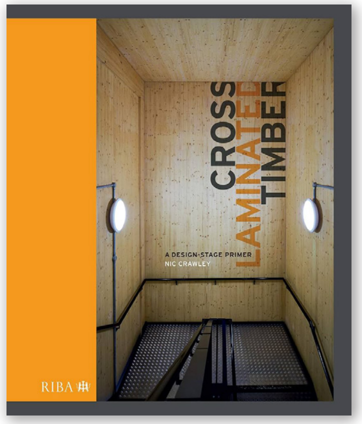

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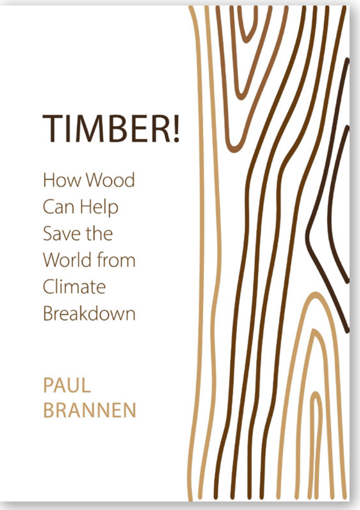

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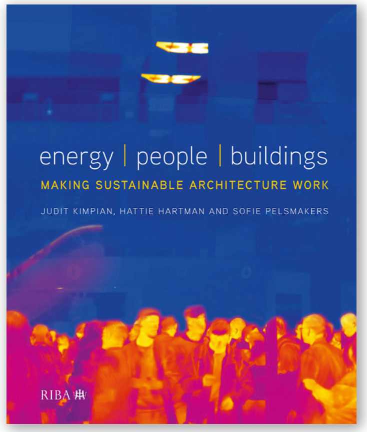

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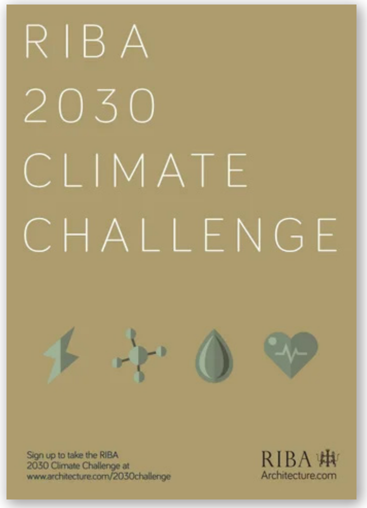

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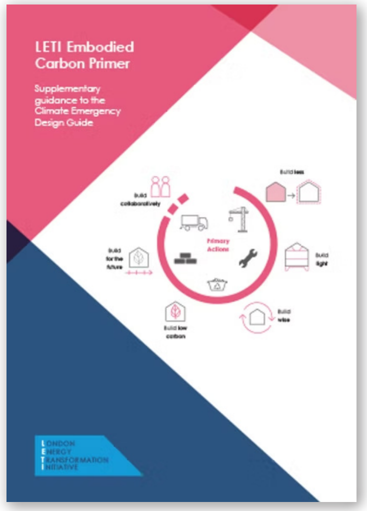

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List of Figures

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Abbey Wood Station

Cambridge Central Mosque

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Rye Apartments

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Sutton Harris Academy

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