100 PROJECTS UK CLT

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FOREWORD

While cross-laminated timber (CLT) appears to be finally entering the mainstream, there is considerable inertia in the construction industry that impedes the greater adoption of this truly innovative material. The benefits are clear - building in timber is quick, clean, and easy. It can be achieved with a measured accuracy and lack of noise, waste, or need for material storage space. It has notable benefits in terms of warmth, acoustics, and structural efficiency. In a world ever more concentrated in urban areas, timber is the basis for safe and healthy cities composed of exceptionally designed and responsibly constructed buildings.

The only surprise to us is that the uptake in mass timber has not been faster. Historically there has been a lack of interest in developing construction technology - a serious problem for our field, and for the world at large. If one reflects on the massive demand for housing, the fact that our industry is responsible for such huge energy use and consequent carbon emissions worldwide, and the tremendous influence our industry has over the overall GDP of the United States and all nations, the question is obvious: Why are we not encouraging governments and the building industry world wide to invest in solutions that will solve the problems that affect our society as a whole? And beyond that, can we afford not to?

If we're going to solve big problems within the architectural realm, our society needs to invest in finding solutions. There is no singular voice or all-powerful entity that defines our profession's response to the greatest challenges of our time. As a result, we need to amass our voices and generate a change of attitude towards research and innovation into construction.

The work illustrated in this book is the product of a few committed professionals who have labored to prove to clients, contractors, and authorities that any code requirements that are met by concrete and steel can be met and exceeded by timber. These projects start to demonstrate a timber architecture with its own form of expression, perhaps one that will inspire more of our contemporaries to take a step towards solid timber.

Image: Binderholz sawmill, Austria © Waugh Thistleton Architects

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Image: Spruce logs, Austria © Waugh Thistleton Architects

With thanks to the architects/engineers of the 100 schemes for their generous contributions:

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INTRODUCTION

The world is in the midst of a housing crisis with a global mass migration to cities. The UN predicts that 66% of the world's population will be resident in urban areas by 2050.[1] In order to deal with this flow of people, the way housing is delivered in our cities needs to be addressed with more high density, mid-to-high rise buildings required.

The implications of this in terms of climate change are considerable while urban structures are predominately built in steel and concrete. The production and use of cement is responsible for approximately 8% of the world's CO_2 emissions,[2] a figure that will increase if urban construction trends continue.

At the same time a gradual decline in construction productivity over the past 50 years presents further challenges in meeting the growing demand for homes.[3]

Timber, nature's own building material, is both replenishable and sustainable, offering an alternative way of meeting the growing housing demand. If we build in timber, as opposed to traditional materials with high levels of embodied carbon, we can save an average of 45 tons (40 tonnes) of CO_2 per dwelling.[4] At a global scale this can make a vital difference.

Traditionally, timber has not been used for high density buildings. However, the recent development of mass timber products has enabled timber to compete structurally at scale. Highly engineered products that overcome many of the issues associated with traditional timber frame have put wood construction back in the running.

This report sets out a study into 100 of the most significant buildings constructed from CLT in the United Kingdom over the past 15 years. We have contacted a wide range of individuals and businesses to interview them about their experiences building in CLT. The opinions have been collated and the findings set out in these chapters. Following these we have appended details of the 100 projects from the study and the names of the consultants, contractors and clients involved.

Image: Softwood forest, Austria © Waugh Thistleton Architects

CLT

The emergence of cross-laminated timber (CLT) over the last two decades has provided a viable alternative to concrete and steel construction.

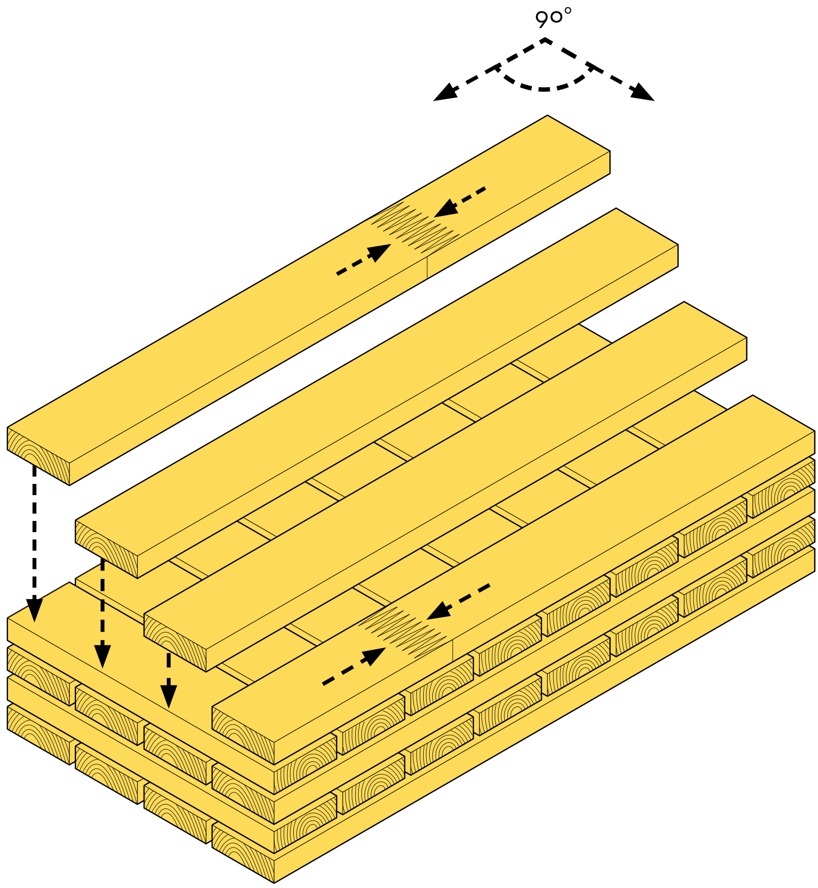
Devised less than twenty five years ago, CLT is a modern timber product, which utilizes a range of species and grades for high performance applications. Cross-laminating is a way of optimizing varying grade softwood to create boards with a high and predictable strength.

CLT panels consist of layers of structural lumber boards stacked in perpendicular layers and glued together under high pressure. A cross-section of a CLT panel is typically fabricated with three to nine layers of boards. By alternating the orientation of the layers of wood, expansion and shrinkage in the plane of the panel is minimized. The result is a considerable increase in stability and structural capacity.

The engineered composite formed through the lamination enables taller, stronger, more stable and safer timber structures that are able to comply with the more onerous demands of high-density building. In this way the multiple issues that have prevented timber frame from entering urban typologies can be overcome.

Broadly speaking, using CLT allows us to construct lighter, better quality buildings, more quickly, with reduced foundations and fewer deliveries to site. This method of construction leads to safer, cleaner, quieter sites, with a reduced number of workers and consequently less nuisance to neighbors in a dense urban site.

The material itself contributes to thermal and acoustic insulation and has verifiable health and well-being benefits. The timber structure locks carbon within its fabric, an intrinsically sustainable and modern approach to construction that produces high quality, high performance buildings.



HISTORY

CLT has its origins in the traditional timber technologies of central Europe and Scandinavia. Modern CLT resulted from joint research between industry and academia in Austria in the mid 1990s and its development has been supported by ongoing research.

In the early years, a few small timber manufacturers in the sub-Alpine regions of Germany, Austria and Switzerland experimented with the new composite and it was used in the construction of buildings up to three storeys.

In the early 2000s, manufacturing and construction techniques had matured enough for full-scale production to begin. The use of CLT spread across Europe and developed particularly in the UK.[5]

As the reputation of the technology has spread, other European countries have begun to set up their own manufacturing facilities.

MANUFACTURE

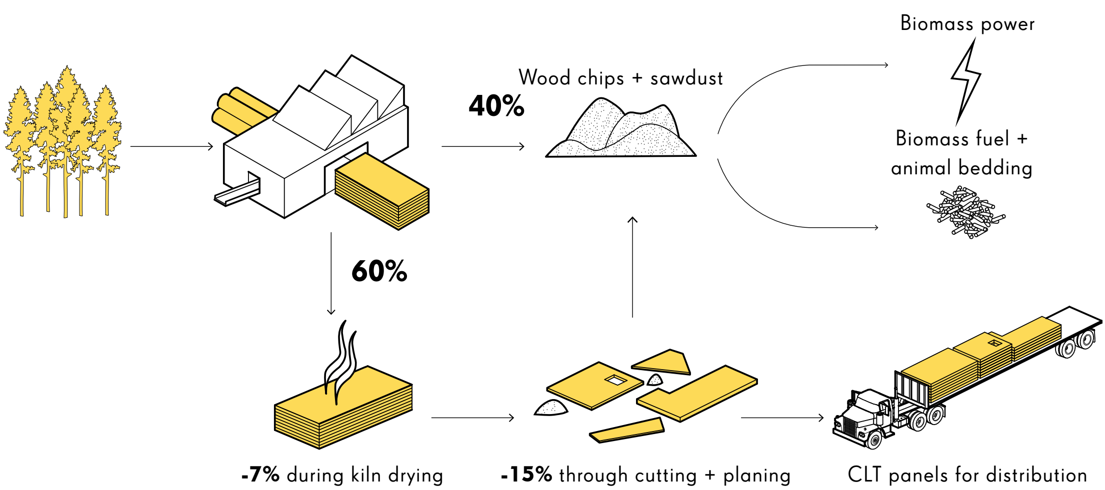
CLT is made from boards of timber, approximately 1-2 inches (20-40mm) thick, which are sorted, finger jointed together into long strips and arranged side by side to form layers. These are glued and pressed to form panels of multiple layers (minimum of 3). Each layer is at 90 degrees to the one before, forming the cross-lamination.

Lumber boards are kiln dried to a moisture content of 10-14%[6] which assists with adhesion and reduces dimensional variations and surface cracking. Defects that influence the strength of the boards, such as large knots, are removed and the boards are trimmed and finger jointed to obtain the desired lengths and quality of lumber.

The panels are assembled by placing the boards side-by-side to form solid wood layers. Each successive layer is laid perpendicular to the preceding layer with adhesive being applied between layers. Once assembled the board is then pressed, in either a large hydraulic or vacuum press, and finally cut to size and/or milled to specification.

In Europe, two glues are typically used in CLT production: PUR, polyurethane based adhesives, or, less commonly MUF, Melamine-Urea-Formaldehyde based. PURs are preferred as they are solvent and formaldehyde free ensuring low toxicity and aiding future re-use or recycling, however the adhesive selection can be influenced by fire requirements.[7]

A test of five different CLT panels indicated no impact on internal air quality by the emission of volatile organic compounds (VOCs) from the CLT.[8]



The production of CLT is a closed loop process in which most waste is reused. The diagram shows the principal activities and efficiency.

CLT is produced at a variety of qualities to meet the requirements of various applications. Generally, this range is non-visible quality (NVQ), industrial visible quality (IVQ), and visible quality (VQ), decreasing in visual imperfections and increasing in appearance quality respectively.

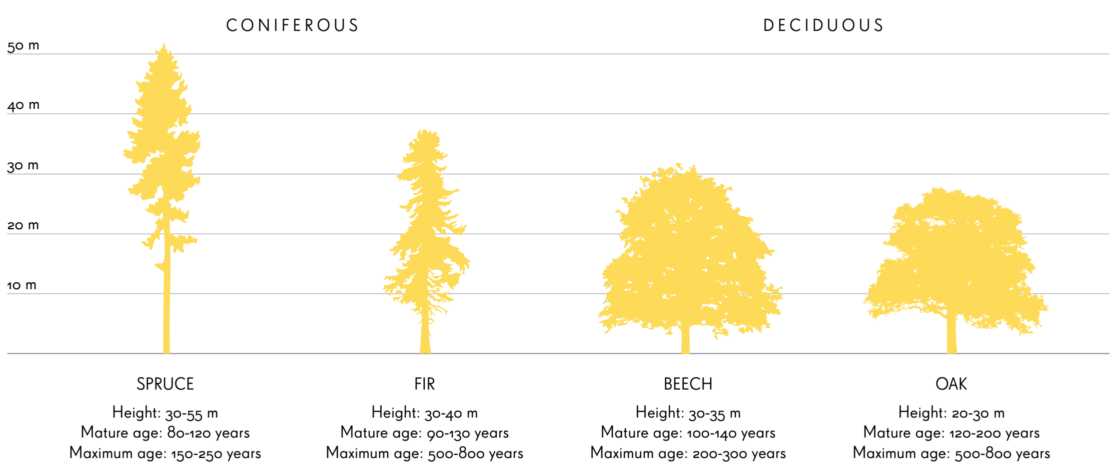
The various manufacturers produce panels of different dimensions, the size of which is impacted by the constraints posed by transportation. While larger panels can be manufactured, their delivery can require special measures such as notification of authorities, road lane closures and police escorts, adding complexity and cost.

THE TIMBER

The timber species that are typically used for CLT are coniferous, evergreen softwoods predominantly Spruce, with varying quantities of Douglas Fir, Western Larch and Pine.[9]

A typical tree harvested for CLT will be around 80 years old and 100ft tall.[10] Sawmilling has a yield rate of around 60% by volume. The kiln drying, planing and cutting causes a further 25% loss. As a result, from every 100ft^3 of log around 45ft^3 of CLT can be produced (0.43m^3 CLT from 1m^3 log).[11]

In most CLT plants the lost material is not wasted - all of the offcuts and sawdust are processed into co-product and biomass that is used to run the factory equipment, the kiln and provide fuel for local communities.[12] This is an optimized process that allows most production to be self-sufficient in terms of energy use.



Comparing the fast growing softwoods used in CLT manufacture with typical hardwoods.

FORESTRY

The Forest Stewardship Council (FSC) and Program for the Endorsement of Forest Certification (PEFC) are certification bodies for the forestry industry. In addition to country regulations, third-party certification confirms that forests are managed in a responsible and sustainable way ensuring diversity, supply and good conditions for workers. Across the world over 1 billion acres of forest is certified, with 16% of this having both PEFC and FSC certification.[13]

This certification is only awarded to products when chain of custody certificates demonstrate that all companies that have handled and processed the timber are accredited. In this way a fully sustainable industry is maintained.

Most CLT manufactured in Europe is produced from timber grown and harvested in Austria and Germany. Both are heavily forested at 48%[14] and 32%[15] respectively, with established forestry industries.

Despite felling, forest coverage in Austria and Germany is increasing year on year.[16] The managed forests from which the timber for CLT is sourced are contributing to an increase in forest coverage. Controlled harvesting from these forests must be distinguished from global concerns of deforestation.

Timber is the only mainstream construction material that can be considered as truly replenishable due to the speed at which it grows. PEFC and FSC are the most established regulatory and certification bodies for a construction material's sourcing ensuring the production of timber is fully sustainable.

In Austrian and German forests alone, enough timber is grown within one hour to produce the CLT required for Dalston Works (pg. 228-229), currently the largest timber building in the world. On this measure, an average dwelling of 1,000ft^3 (30m^3) would be grown every 20 seconds with the 2,440,000 ft^3 (70,000m^3) of CLT used for the 100 case studies growing in 14 hours.[17]

Image: Softwood forest, Austria © Waugh Thistleton Architects

CLT BUILDINGS IN THE UK

The UK has one of the most diverse range of CLT buildings in the world. The reasons behind this are multiple and varied, however one key driver is the nature of the legislative structure that governs construction in the UK.

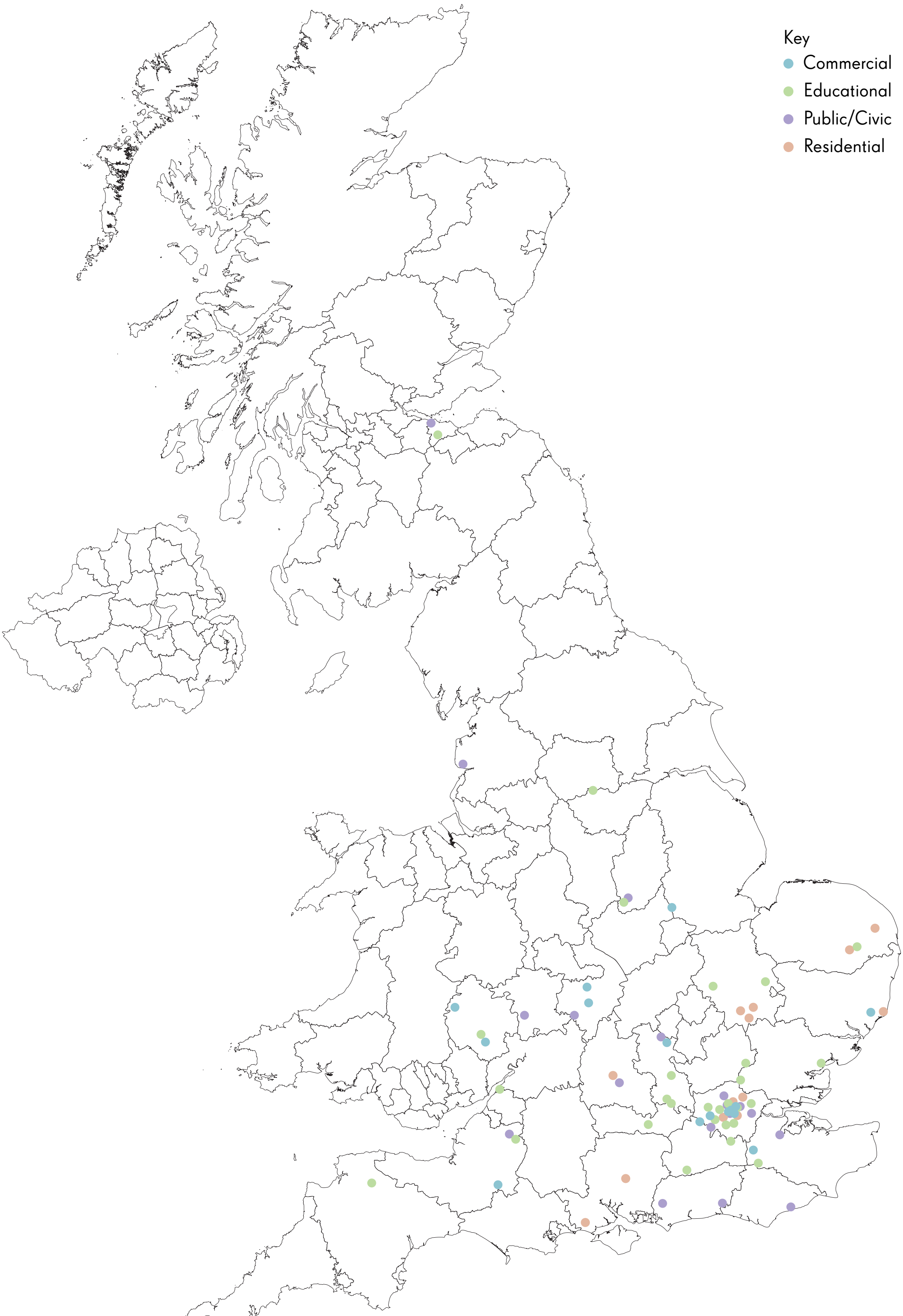
The construction regulations of most countries define specific parameters to which the design must adhere. These regulations will tend to dictate the maximum height for buildings constructed from a combustible material, such as timber. Typically, a maximum number of storeys is prescribed for a fully exposed, partially exposed and fully encapsulated structure. In such environments, the limits can only be increased by a change in the law.

In contrast, the UK building regulations are descriptive rather than prescriptive. They indicate a series of performance requirements and it is the responsibility of the design team and consultants to demonstrate that the proposed solution meets these criteria.

CLT buildings in the UK have to meet the same performance criteria as other building methods and the uptake has not been a completely smooth and effortless journey. This modern method of construction has been advocated and pioneered by architects and engineers across the UK who have gradually overcome the various barriers that have stood in the way.

The extensive portfolio of CLT buildings in the UK demonstrates how engineered timber has and can be used across a range of sectors. Each of the 100 schemes detailed demonstrates an application of CLT and sets a precedent to further the use of CLT in the UK and the rest of the world.

The map of the United Kingdom shows the locations of the 100 case study projects.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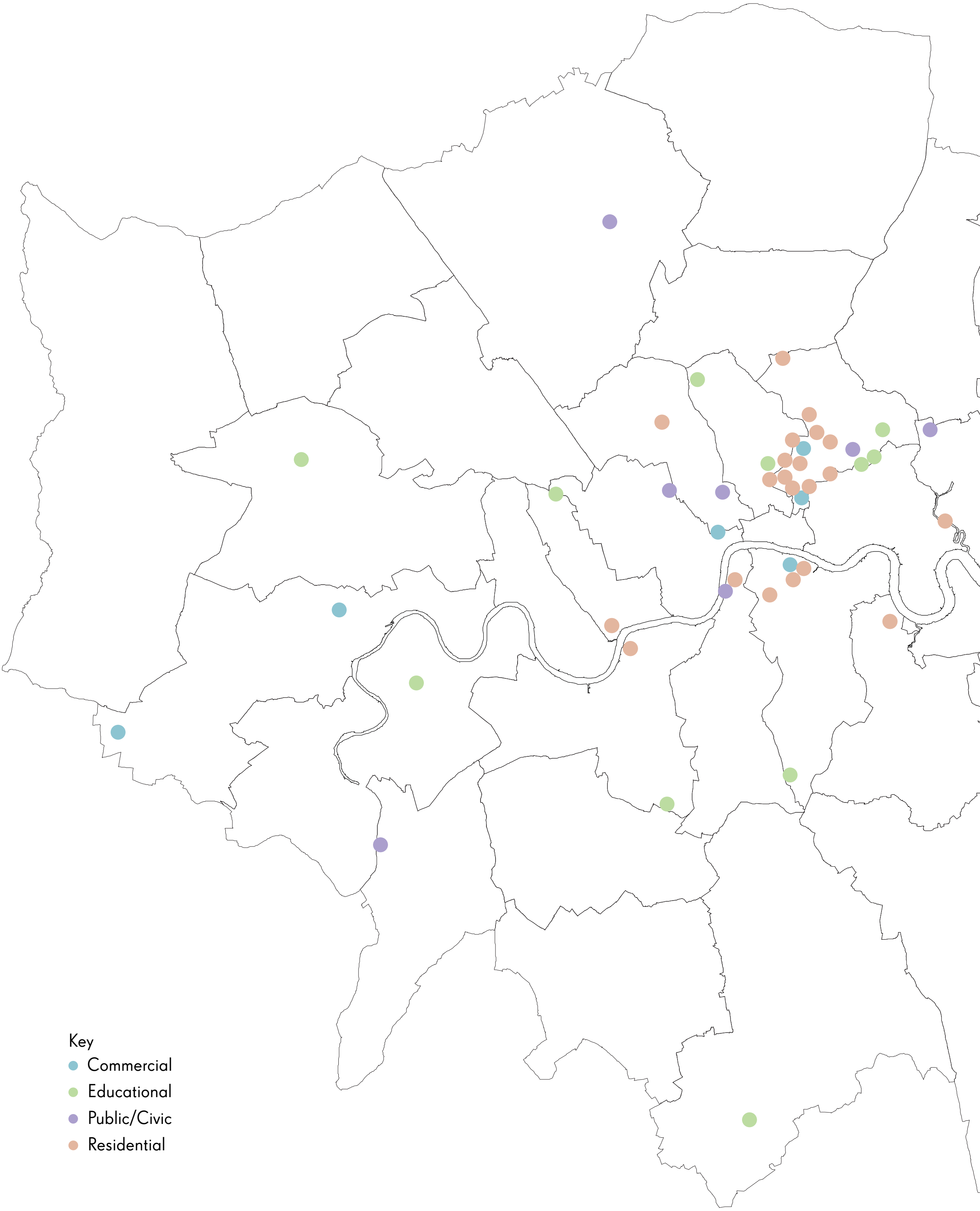

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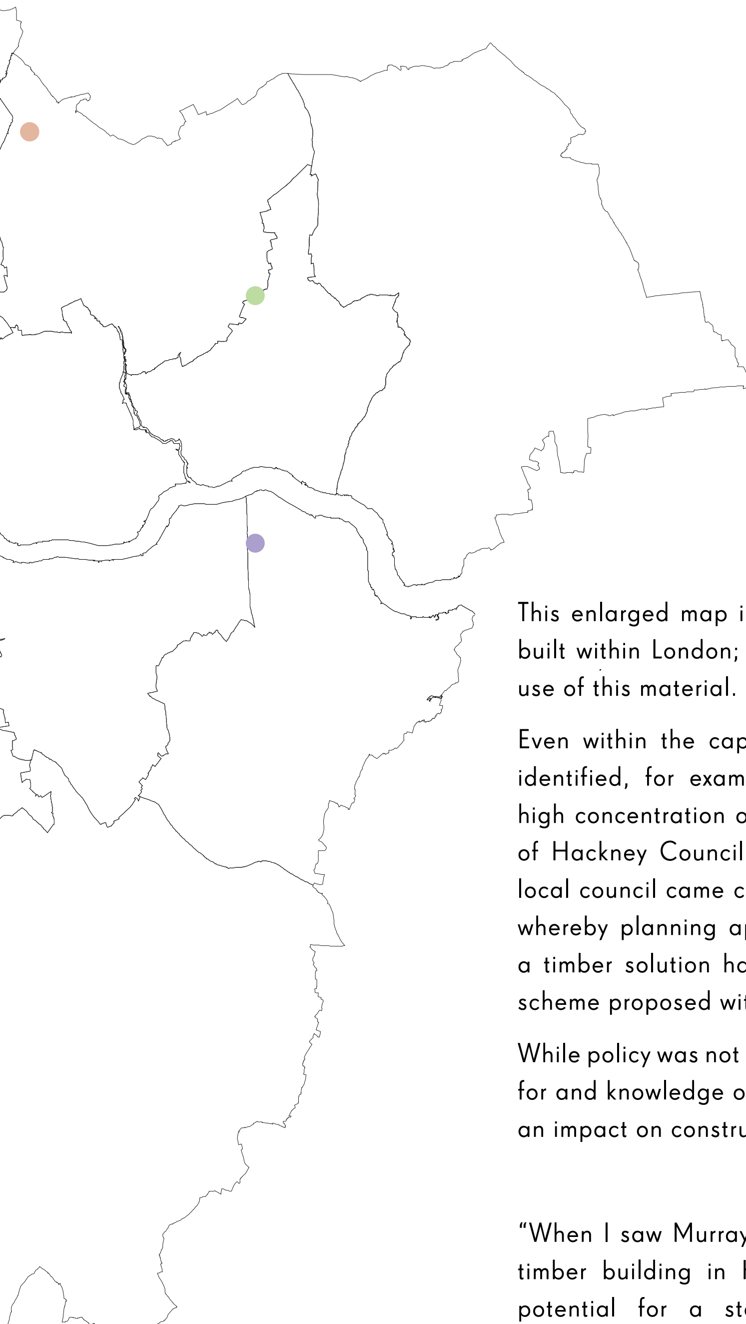


This enlarged map illustrates the spread of the 48 case studies built within London; which has become a key focal point for the use of this material.

Even within the capital, hot spots of CLT construction can be identified, for example the London Borough of Hackney. This high concentration of engineered timber buildings is a reflection of Hackney Council's commitment to sustainability. In 2012 the local council came close to implementing a 'Timber First' policy,[18] whereby planning applications would have to demonstrate that a timber solution had been investigated as an option for each scheme proposed within the Borough.

While policy was not implemented it is evident that to a preference for and knowledge of timber within the local government has had an impact on construction within the Borough.

"When I saw Murray Grove, the world's first 9 storey residential timber building in Hackney, it was clear that there was real potential for a step-change in sustainable construction. I am delighted and proud that Hackney has played a part in the story of tall timber buildings. I hope this will encourage others to embrace engineered timber in construction."
Councillor Vincent Stops, Hackney Council.

Endnotes

1 United Nations, *World Urbanization Prospects, The 2014 Revision, Highlights* (New York, United Nations, 2014).

2 PBL Netherlands Environmental Assessment Agency and European Commission Joint Research Centre, *Trends in Global CO_2 Emissions, 2016 Report* (The Hague, PBL Publishers, 2016), p.64.

3 National Society of Professional Engineers, *Construction Productivity in Decline*, 2014. <http://www.leanconstruction.org/media/docs/PEJune14_Construction.pdf> [accessed 20 September 2017].

Cardiff Garcia, *'The remarkable productivity stagnation of the US construction sector', Financial Times,* 2014 <https://ftalphaville.ft.com/2014/04/15/1821522/the-remarkable-productivity-stagnation-of-the-us-construction-sector/> [accessed 20 September 2017].

4 Mike Berners-Lee, 'What's the carbon footprint of... building a house', The Guardian, 2010 <https://www.theguardian.com/environment/green-living-blog/2010/oct/14/carbon-footprint-house> [accessed 8 September 2017]. Embodied carbon figures from a cross section of CLT case study projects.

5 FP Innovations and Binational Softwood Lumber Council, *CLT handbook: cross-laminated timber / edited by Erol Karacabeyli, Brad Douglas, U.S. ed.* (U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Binational Softwood Lumber Council, 2013).

6 Questionnaire from Kay Hartmann, KLH UK, 11 September 2017.

7 Questionnaire from Daniel Kreissig, Zublin Timber, 22 September 2017.

8 FP Innovations and Binational Softwood Lumber Council, *CLT handbook: cross-laminated timber / edited by Erol Karacabeyli, Brad Douglas, U.S. ed.* (U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Binational Softwood Lumber Council, 2013).

9 Questionnaire from Kay Hartmann, KLH UK, 11 September 2017.

10 proHolz Austria, Wald in der EU, *Zuschnitt*, No. 51 (2013), pp.15-16.

11 Email from Christof Richter, Research and Design at Binderholz, 05 April 2017.

12 KLH UK, *Frequently Asked Questions,* 2017 <http://www.klhuk.com/media/11553/frequently%20asked%20questions_05042011_1.pdf> [accessed 10 July 2017].

13 PEFC, *Facts & Figures,* 2017 <https://www.pefc.org/about-pefc/who-we-are/facts-a-figures> [accessed 20 September 2017].

14 Republic of Austria, Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW), *Sustainable forest management in Austria, Austrian Forest Report,* 2015 <https://www.bmlfuw.gv.at/english/forestry/The-Austrian-Forest-Report-2015--Austria-s-forests-receive-top-grades.html> [accessed 19 September 2017].

15 Federal Ministry of Food and Agriculture (BMEL), *The Forests in Germany, Selected results of the Third National Forest Inventory,* 2014 (Translation 2015) <https://www.bmel.de/SharedDocs/Downloads/EN/Publications/ForestsInGermany-BWI.html> [accessed 19 September 2017].

16 BMLFUW, *Austrian Forest Report,* 2015. BMEL, *The Forests in Germany,* 2014.

17 BMLFUW, *Austrian Forest Report,* 2015. BMEL, *The Forests in Germany,* 2014.

18 Will Hurst, *Hackney moots 'timber-first' planning policy,* Building online, 17 May 2012 <http://www.building.co.uk/hackney-moots-'timber-first'- planning-policy/5036737.article> [accessed 20 August 2017].

BENEFITS

As humanity reassesses its relationship with the planet from one of exploitation to one of investing and protecting our natural assets, so we transition from using materials that are extracted from the ground and pollute the atmosphere, to prioritizing the use of that which is naturally grown. This process will start to reverse the damage to the environment caused by mass global industrialization over the last two centuries.

Trees provide us with an abundant, replenishable source of material. When used in buildings, timber offers unsurpassed benefits to the health and wellbeing of those involved in the construction, those living nearby and those that live or work inside the completed building.

In terms of the planet, one of the greatest attributes of timber is that it absorbs carbon during growth. By using more timber in the construction of our buildings we can remove increased amounts of carbon from the atmosphere. By producing buildings that act as carbon stores, we can make a significant contribution to carbon reduction and help to mitigate the impact of climate change.

Image: Roundwood, Austria © Waugh Thistleton Architects

LIFE-CYCLE ANALYSIS

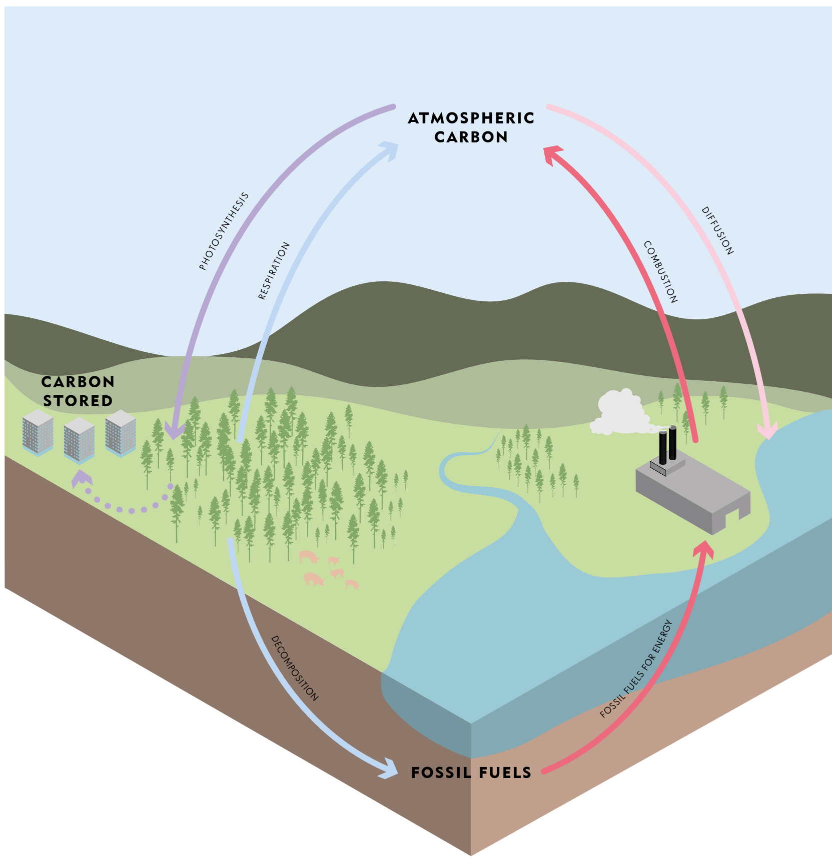
Carbon exists throughout the planet as reservoirs - forests, oceans and open land have significant potential for both storing and emitting carbon. The constant movement of carbon between these various states is known as the carbon cycle. Balanced levels of carbon in the atmosphere are maintained through absorption and emission on the surface of the planet.

The recent increased combustion of fossil fuels that had stored carbon for millennia has disrupted the carbon cycle, increasing the concentration of carbon in the atmosphere and creating change in our climate. Given the time scale over which these stores were created, the released carbon will not be re-absorbed at a fast enough pace to reverse the damage already caused and to stop severe climate change.

Comparatively the carbon cycle within a forest is dramatically shorter with carbon storage within trees taking decades as opposed to millennia. As trees grow they absorb carbon dioxide from the atmosphere for photosynthesis, they then release the oxygen and store the carbon within the wood. As a tree approaches full size the rate of this carbon sequestration plateaus. Eventually the tree will die and decay slowly releasing the carbon back into the atmosphere, a natural part of the lifecycle of a forest.

In managed forests the trees are felled before the end of this lifecycle. The carbon remains within the harvested timber. For each tree that is felled others are planted in its place. Additional planting year on year ensures a net increase in the carbon stored within managed forests despite harvesting.

All timber products, including CLT buildings, act as carbon stores. Effectively, when we build in timber from sustainably managed forests we are increasing the capacity of the world's carbon sink. The scale of today's construction industry offers the opportunity to create a new carbon reservoir within the fabric of timber buildings.

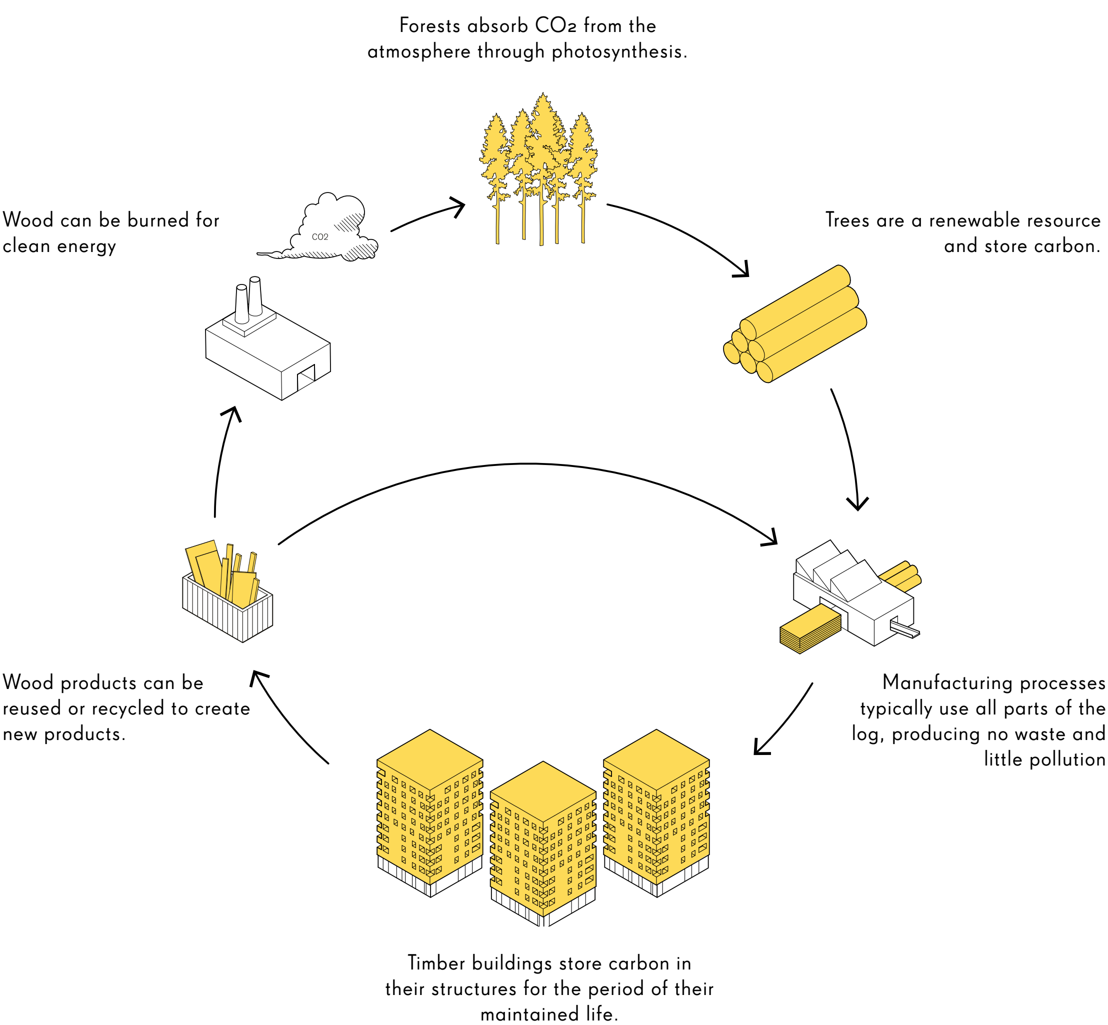


The Carbon Cycle - it is estimated that there is about 30% more carbon dioxide in the atmosphere today than there was 150 years ago. Ice cores show that there is now more carbon dioxide in the atmosphere than there has been in the last 420,000 years.

CIRCULARITY – END OF LIFE SCENARIOS

As part of the overall impact of a building, the whole life carbon cost should be considered, especially where the stored carbon is a factor. We must consider that in the next 50 years some of the early CLT buildings will be decommissioned and, while the timber can be used for fuel, it would be preferable for the carbon storage to be extended through reuse or recycling.

As a new technology there are few precedents set for end of life recycling or reuse. However, at this early stage in CLT's development we have the opportunity to plan for this now. We can design with the objective of maintaining the CLT as a carbon sink when a building is decommissioned; designing for reuse and recycling, rather than energy production.



© Yugon Kim

Contaminants are the most significant obstacle to wood recycling. Research by The Waste and Resources Action Program (WRAP) outlines the cost and time implications of removing contaminants, and highlights that preventing contamination in the first place is the best and easiest method to ensure that wood can be recycled and reused.[1]

The glues typically selected for CLT manufacture are low hazard, meaning that the panels that leave the factory can be recycled or reused. By keeping re-use in mind during the design stage, designers can ensure that the CLT is not treated with toxic products, which would inhibit recycling.

An example of how this is achieved is the Sky Health and Fitness Centre (pg.250-251). Structural and fire engineering design allowed the CLT to be exposed whilst avoiding the need for almost all applied spread of flame treatment. Considering the reuse at the early stage of design has ensured that the panels used within this scheme have a greater potential for recycling at the end of the building's life.[2]

The cascade principle is based on the idea that the value of a product, both in terms of its material and capital should be maintained for as long as possible to maximize a material's useful life. In essence a CLT panel is a high quality and valuable product that can be repeatedly processed into lower quality products with use as biofuel being the last and final option. The benefit here is that each new life the material is given extends the period for which it remains a carbon store.

Sky Health and Fitness Centre, dRMM © Paul Carstairs/ARUP

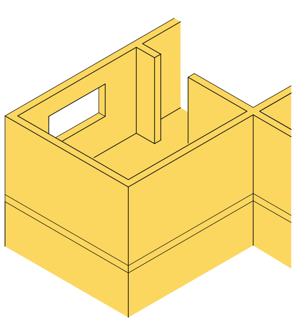
REDUCING CARBON INTENSIVE MATERIALS

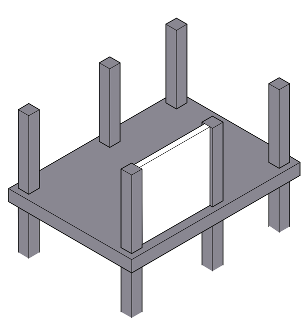
FRAME SUBSTITUTION

The processing, manufacture and transportation of modern timber products result in a significantly lower embodied carbon figure than other, traditional construction materials.

It is not straightforward to directly compare the embodied carbon of one ft^3 or a pound of a specific material as the volume or weight of material used for the same building will vary depending on the structural system and performance. Research studies have compared the embodied carbon of concrete, steel and hybrid structural frames, all generally illustrating a similar level of embodied carbon, at around 55lbs.CO_2/ft^2 (225kgCO_2/m^2) for the superstructure of an open plan commercial type building.[3] This embodied carbon figure is for 'cradle to site' incorporating extraction, processing and delivery.

Comparatively based on the open plan pure timber commercial buildings in our study, the equivalent embodied carbon of the timber structure, not including the sequestered carbon, is 12lbs.CO_2/ft^2 (63kgCO_2/m^2). By substituting a CLT frame for a concrete or steel structure the embodied carbon of the building can be vastly reduced.



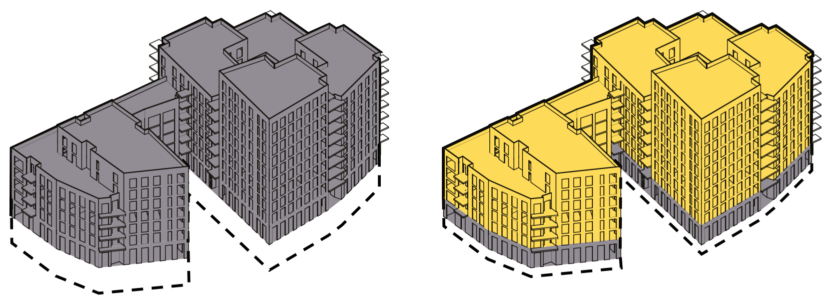


The diagrams illustrate that a CLT frame includes internal walls, as well as structure, compared to a reinforced concrete frame, which requires infill.

REDUCED FOUNDATIONS

The design of any engineered timber building must ensure that the timber is protected to avoid contact with moisture that could cause mold growth or decay. In most instances, concrete or other masonry materials are used for the foundations of timber buildings.

While timber should rarely be used for below ground works, the weight of a CLT structure can significantly reduce the requirement for foundations, resulting in an overall reduction in the volume of concrete used for the ground works as compared to a traditional build.[4]



The diagram indicates an approximate reduction in the raft foundations required for a CLT version of the Dalston Works scheme.

REDUCED SECONDARY STRUCTURE AND FINISHES

In contrast to most frame technologies, CLT panels can be utilized to form entire walls, floors and roofs which reduces, and in some cases removes, the need for any secondary structure. In addition, when exposed as an internal finish, the use of CLT reduces the volume of finishing materials required to line walls and form suspended ceilings.

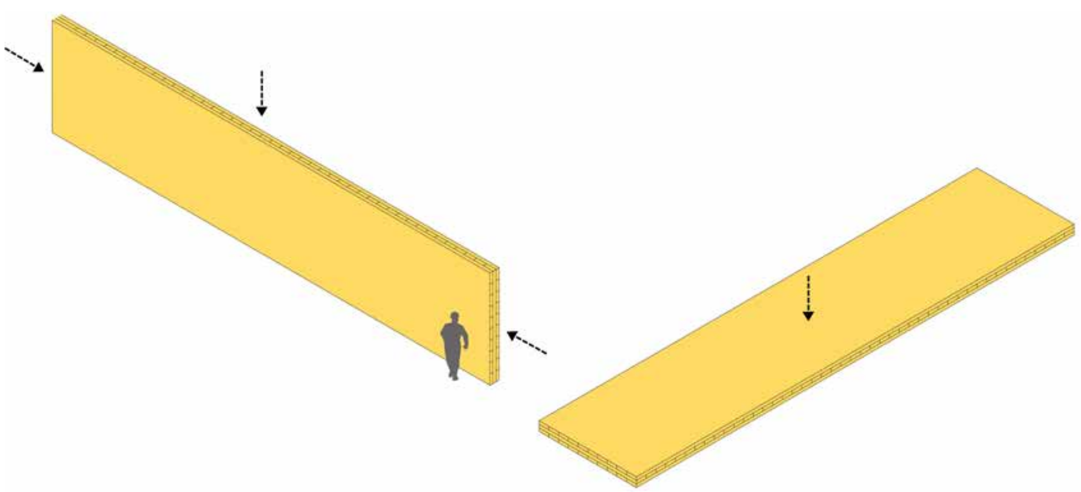
Reducing the volume of high-embodied carbon secondary materials, such as dry wall or aluminium cladding, can significantly further reduce the carbon footprint of the building.

STRENGTH AND RESILIENCE

Cross-laminated timber and glulam offer high strength to weight ratios that in many cases equal those of steel and reinforced concrete.[5]

CLT panels provide high levels of strength throughout the structure. This strength is demonstrated both in-plane, resisting shear forces and carrying load and out-of plane, where a panel acts as a bending slab. This two-way load resistance is similar to the behavior of reinforced concrete.[6]

Additionally, the cross lamination ensures high levels of dimensional stability with little deformation of the panels to in-plane load. Out-of-plane load, and in particular localized compressive load, for example in a floor slab at the base of a wall panel, is more likely to result in deformation, however this is able to be calculated precisely and accounted for within the dimensioning of an overall structural frame.



CLT can resist load both as a beam (ie. in-plane), or a slab (out-of-plane)

Where the compressive load is likely to be high, for example at the lower levels of a multi storey building, slab panels can be reinforced by using localized grout pockets or by driving screws or hardwood dowel into the timber as reinforcement.

Innovative engineered timber panels are currently under development which include hardwood and carbon fiber layers within the panel leading to substantial increases in strength.

FIRE

A key advantage of CLT is its inherent fire resistance. In most cases, the charring of the timber surface during a fire protects the material beneath which maintains its structural integrity. In this way, significant structural fire protection can be achieved within the material items and CLT panels can be produced with fire resistances of up to 60 minutes.

In practice, a combination of the timber charring and fire resistant boards are commonly used to achieve the necessary fire rating.

Great care should be taken with regard to the resistance to fire and the potential for escape from all buildings, whatever their construction material. The fact that timber is a combustible material encourages the designer of timber buildings to pay particular attention to these issues, although this should be the case for all buildings.

SEISMIC ACTIVITY AND EXPLOSIONS

Under exceptional loads, such as from earthquakes, CLT and its connections flex and absorb energy from the vibrations, acting as a damper. This is in contrast to concrete and steel, which are more likely to fracture or disintegrate under these forces.[7]

The most robust study to date to quantify the seismic behavior of CLT construction is the SOFIE project undertaken by the Trees and Timber Institute of Italy. A seven storey structure was shown to be able to withstand significant sustained vibration, up to the strength of the Kobe earthquake of 1995 without any significant damage.[8]

Last year the U.S. Department of Defense subjected CLT and other materials to a series of live blast tests which showed in slow motion the way in which the timber bows and absorbs much of the energy of the blast, resulting in little permanent damage.[9]

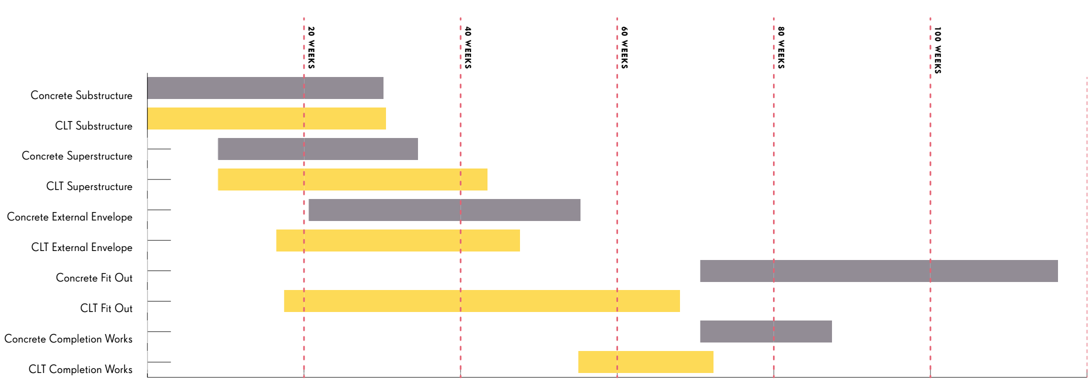
BENEFITS IN CONSTRUCTION

SPEED

The program savings that can be achieved using CLT are generally considered the most significant benefit and biggest cost saving associated with this system of construction. Typically, the overall construction of a CLT scheme will be 20% faster than an equivalent scheme in reinforced concrete.

This time saving is not only the result of the speed at which the pre-fabricated elements of CLT are erected, but of the significant time savings in the later stages of construction. These gains are principally acheived through the accuracy of the finished structure, the structural stability, concurrent working and the ease of fastening into timber.

Both installation of the prefabricated CLT panels and subsequent works are easier, quieter and safer, reducing or completely avoiding wet trades and reducing the number of personnel required to erect the superstructure by around 50-70%.[10]



The Gantt chart indicates the approximate program adjustments that would be expected for a CLT scheme compared with a traditional reinforced concrete build.

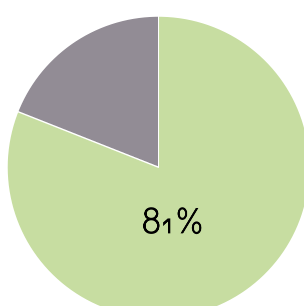
KLH UK lists the following approximate time savings for various aspects of the build:[11]

- Services (MEP) – approx. 30-50% faster
- Dry liners – approx. 20-30% faster
- Window & door installers – approx. 20-30% faster
- Insulation installers – approx. 20-30% faster
- Cladding installers – approx. 20-30% faster

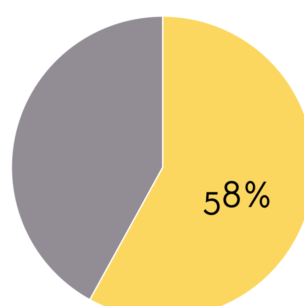
Reduction in program time has financial benefits in reducing on-site overheads, shortening loan terms, personnel costs and allowing for the earlier occupation of buildings.

The reduced program offered by CLT can also enable time critical projects to be realized. This can be a crucial consideration for many projects, including schools, for which funding periods can be set and term time dates and new intake levels fixed.

81% of the education case studies stated that time savings were one of the primary factors in the choice of CLT for their project.



Education projects that highlighted speed as a primary benefit



Projects accross all the sectors that highlighted speed as a primary benefit

WASTE AND LOGISTICS

A typical CLT structural frame is prefabricated off-site and includes openings and service voids. As a result of this there is almost no waste from the erection process of the structure. This can have benefits in terms of the site operations in that there is no need to take up large areas for site waste storage prior to disposal.

Savings in site logistics are also achieved from the ability to crane panels directly and quickly into place from a delivery vehicle. Frequently the erection of the frame can be undertaken using a mobile crane eliminating the requirement for a tower crane, with the expense and additional structure they require.

Waste from one week during the erection of the CLT frame at Stadhaus/Murray Grove

HEALTH AND SAFETY ON SITE

With the reduction in material and weight, there is a reduction in the labor required to construct a pre-fabricated CLT frame, and the health and safety considerations on site can therefore be commensurately reduced. Furthermore, the completion of entire solid walls concurrently with floors reduces the risk of falls from height and gives a dry and warmer working environment. Where stairs are also included in the frame, each completed level offers a safely accessible workspace with limited need for additional protection.

The construction of CLT buildings is quieter and creates less dust and waste than traditional construction sites. This makes for better working conditions for construction workers and a cleaner local environment, an important issue particularly in urban locations.

In comparison to a concrete or steel construction site, the noise levels from CLT construction are dramatically lower. Because the panels are pre-fabricated to minute tolerances there is no heavy machinery required on site. The majority of work involved in fixing into the timber is achieved with cordless power tools. This makes for both a significantly quieter and less toxic working environment.

Furthermore, the timber itself absorbs airborne vibrations significantly reducing reverberant noise levels both on and off site. The inclusion of external walls within the superstructure means that the majority of the working space is partially enclosed which further limits sound nuisance to neighboring properties.

Deliveries of the structure are also greatly reduced, often by as much as 80%.[12] The effect of construction site deliveries on the urban environment in the UK is becoming an increasingly widely discussed issue. Pollution from engine fumes and tires has been demonstrated to have a major impact on air quality in the urban areas of the UK.[13]

HEALTH AND WELLBEING

In 2015, Planet Ark, an Australian not-for-profit, environmental organisation. published a review of studies analysing the health and wellbeing benefits of wooden interiors in homes, businesses, schools and hospitals.

"We know that workers are less stressed and more productive, students learn better, patients heal faster, and people are generally happier and calmer in indoor areas which contain wooden elements," says David Rowlinson.[14]

The review identified that the increased use of wood has measurable physiological and psychological health benefits. Exposing timber in interiors has a number of measurable health benefits for inhabitants including reduced blood pressure, heart rate and stress levels. Studies also show that living or working in a wooden interior can improve a person's emotional state and their level of self-expression.[15]

In schools, this can include greater levels of attention and receptiveness to learning. At the Ickburgh School (p.136-137), the head noted that the wood had a beneficial impact on the stress levels and behavior of the children.

The review identifed studies that show that the presence of wood in offices can dramatically improve visitor's impression of the company, conveying feelings of innovation, energy and comfort. Companies with timber interiors report higher levels of staff retention, greater levels of productivity and lower levels of sickness.

In addition to the psychological and physiological effects of timber, the use of wood has a beneficial effect on air quality through moderating levels of humidity, absorbing moisture in humid conditions and releasing moisture in dry conditions. This also reduces discomfort from high humidity that often accompanies high temperatures.

Another feature of wood is that it does not become electrically charged, which inhibits the raising of dust, reducing allergens and increasing the quality of life for those suffering with respiratory problems.[16]

Timber surfaces and massive timber panels have an acoustic benefit, absorbing sound and so improving comfort, particularly in more public environments.

DESIGN FLEXIBILITY AND AESTHETICS

A structural system that is entirely timber offers opportunity for new forms of architectural expression. This provides us with an extensive range of innovative and distinctive buildings, many examples of which are included in the case studies in this book.

These illustrate the simple composite action that CLT construction enables, where walls and balustrades can act as beams above slabs and cantilevers can be achieved with the straightforward extension of a slab. Multiple load paths allow engineers to create efficient, well-honed structures, leading to a range of structural possibilities.

At the mixed-use building on Whitmore Road (pg.192-193) the party walls between the apartments at the top of the building act as deep beams holding the roof of the open plan photographic studio beneath. Similarly, the complex folded roof of the house extension at Hunsett Mill (pg.180-181) is designed to be stiff enough to support the first floor which is hung beneath.

The high strength to weight ratio and the low thermal conductivity make cantilevers straightforward to form. Examples within the case studies include the roof of the Queen Elizabeth Olympic Park Timber Lodge (pg.294-295) and the Wedding Chapel in the Tower of Love pavilion (pg.282-283).

The natural beauty of the raw material provides an attractive internal finish with the added expedient of not having to line out the structure. Many of the case studies demonstrate how this advantage has been exploited.

The monolithic Architecture Archive (pg.244-245) exposes almost the entire structure both internally and externally. Similarly, Barrett's Grove (pg. 206-207), a development of six homes, exposes all internal walls and ceilings.

Endnotes

1 Ijeh, I., Recycling Timber: Wasting away, Building online, 28 October 2015 <http://www.building.co.uk/recycling-timber-wasting-away/5078393.article> [accessed 20 August 2017].

2 Adrian Campbell, Change Building, interview by R.Sawcer & K.Walker, London, 14 August 2017, Waugh Thistleton Offices.

3 Cundall Johnston & Partners LLP, Embodied carbon of steel vs concrete buildings, Information paper – 31, 2013 <http://www.cundall.com/Cundall/fckeditor/editor/images/UserFilesUpload/file/WCIYB/IP-31%20-%20Embodied%20carbon%20versus%20steel%20v%20concrete%20buildings.pdf> [accessed 15 June 2017].

4 Gavin White, Ramboll, Interview by A.Thistleton & R.Sawcer, London, 8 September 2017, Waugh Thistleton Offices.

5 Structural Timber Association, Timber as a structural material - an introduction, Structural Timber Engineering Bulletin 1, 2014 <http://www.cti-timber.org/sites/default/files/STA_Timber_as_structural_material.pdf> [accessed 10 July 2017].

6 Gavin White, Ramboll, Interview by A.Thistleton & R.Sawcer, London, 8 September 2017, Waugh Thistleton Offices.

7 Gavin White, Ramboll, Interview by A.Thistleton & R.Sawcer, London, 8 September 2017, Waugh Thistleton Offices.

8 National Research Council of Italy, Trees and Timber Institute, *The SOFIE project,* 2007 <http://www.ivalsa.cnr.it/en/current-projects/edilizia-e-architettura/progetto-sofie.html> [accessed 10 August 2017].

9 Joyce El Kouarti, U.S. Forest Service Office of Communication in Forestry, *Build Better, Stronger, Faster with CLT*, 2017 < https://www.usda.gov/media/blog/2017/04/04/build-better-stronger-faster-clt> [accessed 10 September 2017].

WoodWorks, Wood Products Council, Woodworks Leads Blast Testing Project for Cross-Laminated Timber, 2016 <http://www.woodworks.org/wp-content/uploads/Blast-Testing-News-Update-Dec-12-2016.pdf> [accessed 10 September 2017].

WoodWorks, Video recordings, 2016 <https://www.youtube.com/channel/UCsy22KwkQ-1xUtIfUU2u3fg/playlists?view=1&flow=grid&sort=da> [accessed 10 September 2017].

10 Questionnaire from Liam Dewar, Eurban, 15 September 2017.

11 KLH UK, Frequently Asked Questions, 2017 <http://www.klhuk.com/media/11553/frequently%20asked%20questions_05042011_1.pdf> [accessed 10 July 2017].

12 Questionnaire from Liam Dewar, Eurban, 15 September 2017.

13 Robin McKie, *Smog in the cities: the truth about Britain's dirty air*, The Guardian, 2017 <https://www.theguardian.com/environment/2017/jan/29/pollution-air-quality-london-environment> [accessed 8 September 2017].

14 Damian Carrington, *Electric cars are not the answer to air pollution, says top UK adviser*, The Guardian, 4 August 2017 <https://www.theguardian.com/environment/2017/aug/04/fewer-cars-not-electric-cars-beat-air-pollution-says-top-uk-adviser-prof-frank-kelly> [accessed 10 September 2017].

15 Planet Ark, Make it Wood, Housing, Health, Humanity, 2015 <http://makeitwood.org/documents/doc-1253-wood--housing--health--humanity-report-2015-03-00-final.pdf> [accessed 20 November 2017].

16 Planet Ark, Make it Wood, Housing, Health, Humanity, 2015 <http://makeitwood.org/documents/doc-1253-wood--housing--health--humanity-report-2015-03-00-final.pdf> [accessed 20 November 2017].

Sandra van Dijk, Wood improves are quality, moderates humidity, Climate Control News, 27 March 2017 <http://www.climatecontrolnews.com.au/ventilation/wood-improves-air-quality-moderates-humidity> [accessed 20 November 2017].

DESIGN FACTORS

As a high quality engineered product, the material cost of CLT is typically around 30-40% higher by building volume than traditional structural materials. The cost is determined by a range of factors including the dimensions, quantity and whether conventional hydraulic pressing or more specialist vacuum pressing is required (needing more time and labour), the complexity and scale of the project and the finish or grade or timber used.

While there is a higher apparent cost, a CLT structure provides far more than a basic structural frame. It will usually include external and internal walls, stairs and lift shafts. Additionally, there are a number of consequential savings resulting from the lightness, accuracy and workability of the timber.

A lack of awareness of the potential benefits can result in cost consultants using a base cost per square foot of floor area for the frame, showing CLT as a more expensive solution. Working with an engineer, cost consultant and main contractor experienced in the construction of CLT buildings is key to ensuring the various possible savings are realized and accounted for.

Image: Architecture Archive, Hugh Strange Architects © David Grandorge

OPTIMIZING

To ensure an optimized scheme it is essential to design a project as a CLT structure from the outset. CLT members do not perform in the same way as concrete and steel. Designing with an appreciation of the benefits and restrictions of the system will lead to a far more efficient architectural solution. This approach also ensures that all the associated benefits can be planned for. While schemes can be adapted for CLT at a later stage this can result in missed opportunities and diminished savings.

Key to the delivery of a CLT scheme is the appointment of a design team that is enthusiastic to engage with CLT construction from an early stage in the design process – this was directly identified by nearly a quarter of the case study respondents as a key lesson learned. The following section outlines the ways in which working with the right team can reap rewards.

STRUCTURAL PRINCIPLES

CLT uses a large volume of timber compared with timber frame, which increases the volume of carbon sequestered. Even as a renewable resource designers should be considerate and efficient with materials, optimizing the size of elements.

Typically, a CLT solution up to around four storeys would utlilize more material than needed to perform the structural work required, however the same is often true for concrete frames in low rise schemes.[1] For buildings of this scale, a timber frame or SIPS structure may be more appropriate, solely utilizing CLT panels for the floor slabs and core.

While CLT is often not the most structurally efficient solution for low rise schemes, the other benefits of CLT often merit its use, for example the simplicity of a CLT structure and the performance of the panels and quality of construction.

MATERIAL EFFICIENCY

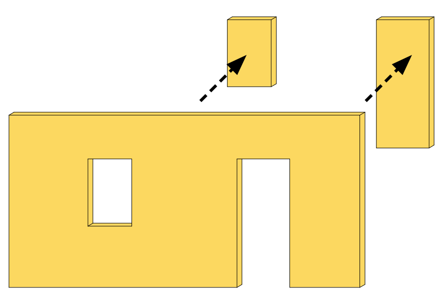
It is evidently advantageous to optimize panel use to reduce material use and therefore cost. Further savings can be achieved thorough progressively reducing the thickness of wall panels up the height of the building which uses less material, reducing the overall loadings.

In addition, floor build-ups in CLT are typically less than those achievable using more traditional methods, which can lead to overall reductions in floor to floor heights. Over a taller building this incremental gain can enable an additional storey to be built within a height limit, or alternatively allow for more generous floor to ceiling heights.

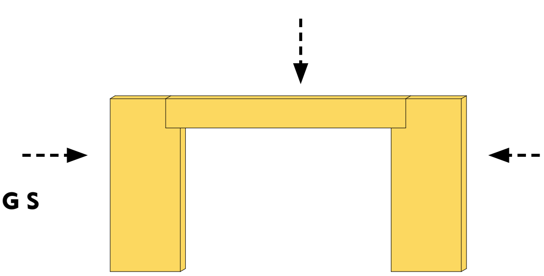
CUTTING AND ROUTING

While basic routing of openings will be included within the cost of CLT panels, more complex cutting can significantly increase costs.[2] An increase in the time spent on the cutting bed, particularly complex routing on both faces, requiring turning or rotating of the panel, will impact the cost of the panels. In many cases, however, this can be offset by material and time savings where site work is reduced.

Another primary consideration when planning openings is the lost material. In most facilities, the off-cut CLT is processed into biomass, however the costs tend to be based on the volume of the full panel.



SMALLER OPENINGS ROUTED OUT



LARGER OPENINGS FORMED

Where particularly large openings are needed it can be more cost effective to form openings from multiple pieces of CLT. The benefits should be considered against the additional lifts on site and additional joints that can increase the construction period and have the potential to reduce accuracy and structural performance.

For most residential scale openings, a small loss of material tends to be the more cost effective option. Working with engineers familiar with the dimensions of CLT panels will ensure openings are designed in the most efficient way.

On occasion these offcuts can be re-used within the scheme itself. For example, in Kingsdale School (pg.106-107) and MK40 Tower (pg.268-269), dRMM used the cut–out material as furniture, retaining the value of the material within the project.

Often more than one project will be nested on a production run to improve factory efficiency. An understanding of the manufacturer's panel nesting process can therefore also result in savings.

TRANSPORTATION CONSIDERATIONS

Transport costs typically represent around 10% of the overall cost of a CLT frame. Transporting panels is most cost effective if they are stacked regularly and compactly with no wasted space and no requirements for wide or long loads, which may require road closures or police escorts. Large cut-out openings or complex shapes can reduce this efficiency and increase transportation costs.

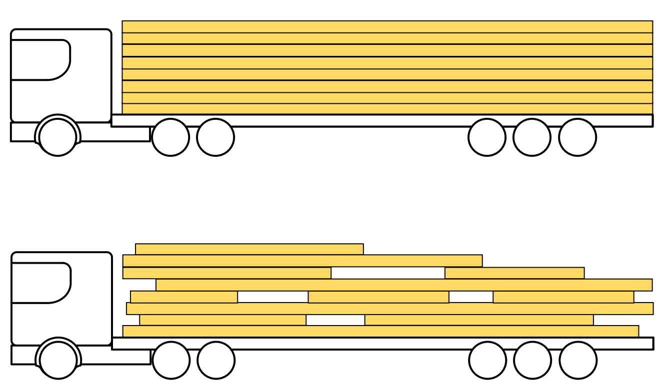
The light weight and prefabricated nature of CLT construction typically offers an enormous reduction in the number of deliveries to site, compared with concrete frame, especially when schemes are designed with an understanding of delivery parameters. In comparison to in-situ concrete frames, around 80-85% fewer deliveries are required for a CLT structure, greatly reducing the impact of site logistics on the surrounding community.[3]

This is particularly beneficial for tight urban sites. Constraints and restrictions to delivery or installation should always be considered at an early stage to ensure the smooth erection of the structure. Parking, loading areas, turning and over-sailing are all issues that should be addressed.

In some projects the delivery and/or installation of the panels is particularly constrained by the site. For example at The Garden Museum project (pg.272-273), the CLT structure had to be erected inside the volume of the existing church with panels brought in through the door. Understanding and acknowledging such constraints from the outset can influence the design by working to a more appropriate 'typical' panel width or length.

Even for more conventional schemes, site access can pose issues or restrict certain delivery vehicles. At Wynch Cottage (pg.156-157), the CLT design was coordinated with the access constraints of the site, but relied on the creation of a new, more easily accessible, road between the mature trees. The CLT delivery strategy then had to be changed considerably when delays on site meant the new road was not completed in time. To avoid further delay to the structure, the panels were double handed to arrive on site via a specialist lorry that could negotiate the tighter route.

Working with a knowledgeable team will ensure these potential issues are raised early and addressed within the metrics of the scheme.

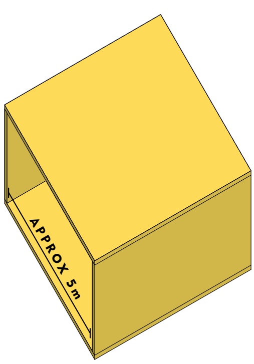


HYBRID SOLUTIONS

Different building types require different structural solutions. It is essential to determine early in the design whether a pure CLT structure or CLT panels combined with other structural materials is the most appropriate solution.

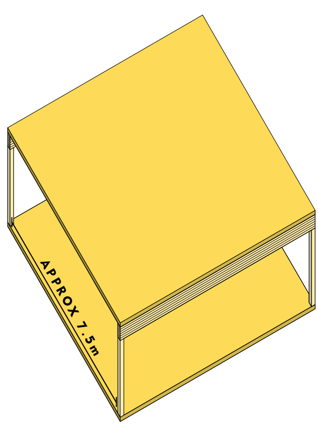
The diagrams illustrate the typical ratio of spans possible where the same thickness of CLT panel is used, by itself, with glulam beams or with steel beams of equivalent depth. Multiple options are possible within each of these structural systems.

Pure CLT solutions create a honeycomb of structural walls and floor slabs resulting in cellular spaces. Optimizing spans to approximately 15ft with a maximum of 25ft (4.5-7.5m) ensures a reasonable thickness of CLT is used. This span is akin to that of most typical domestic rooms making pure CLT solutions particularly appropriate for residential projects. These schemes are easier to benchmark in terms of the expected cost for a CLT frame per ft^2 as the structures are relatively similar from project to project.



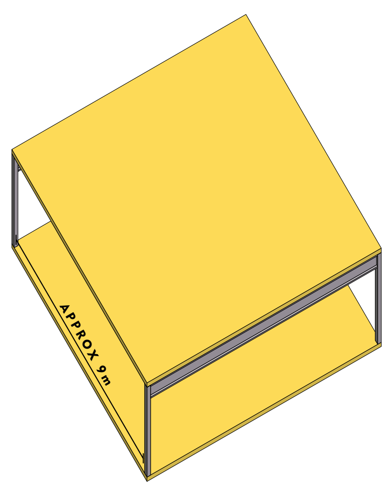
PURE CLT

CLT forms all principal structural elements.



TIMBER HYBRID

Utilizing CLT slabs with glulam columns and beams.



HYBRID

CLT slabs supported by a concrete or steel frame.

Hybrid systems can be used to achieve greater spans without requiring thick timber slabs. Such solutions are typically either CLT with glulam; that is all timber, or CLT with steel and possibly concrete. Other hybrid solutions include the use of concrete cores with CLT floors and walls for the habitable space or glulam and concrete structures. Hybrid solutions using additional materials can require additional contractors and personnel on site and increased co-ordination for the interfaces between materials.

Glulam, steel and precast concrete systems all work well with a CLT frame as they can also be factory produced requiring the same level of detail at the same stage and achieving high levels of accuracy and tolerances. The selection of these material combinations ensures that the use of a hybrid solution does not negatively impact on the time advantages associated with CLT. Glulam has the additional benefit that it is of the same material and so reacts to environmental changes in a similar way which can help to simplify details.

Many CLT suppliers will be able to model and draw steel elements meaning that they can be signed off and ordered at the same time as the CLT, however varying lead times and a lack of flexibility to alter these elements later in the program can be restrictive.

The relationship between structural approach and sector is clear from the data obtained from the 100 case studies. Commercial projects that require more open plan adaptable spaces often use hybrid solutions. Similarly, education schemes typically combine smaller cellular spaces for classrooms, and larger span spaces, for auditoriums and sports halls which are also hybrid, while residential schemes tend to be pure CLT. If the high density residential schemes are separated out from the individual bespoke houses then the percentage that are pure CLT becomes even higher at 70%.

For lower rise applications such as individual dwellings and schools, the reduced structural demands on the CLT can enable some unique and clever approaches to pure CLT frames achieving open spaces of substantial volume.

MATERIALITY

EXPOSED TIMBER

The aesthetic qualities of the wood are often one of the reasons for selecting timber as the structure with the potential for cost savings on wall and ceiling linings adding to the attraction. The visual appeal was reported as a primary factor in choosing a CLT structure for 52 of the schemes, whilst the timber is exposed to varying degrees in 88 of the schemes.

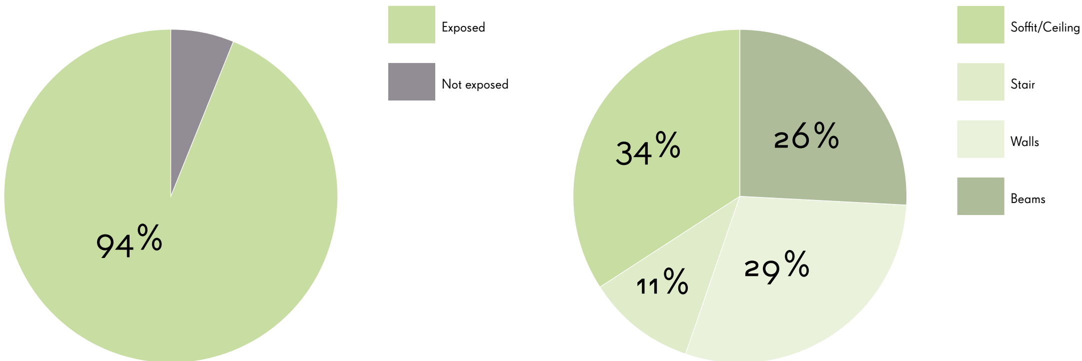
Exposed timber is more prevalent in the education and commercial sectors than other typologies, with it being featured least in mass residential projects. This results from the need to add acoustic and fire protection measures which are most easily achieved through lining and encapsulation of the timber. Furthermore, the onerous provisions for safe escape limit the possibility of exposing areas of timber. This is not the case in single dwellings, with 90% of these case studies featuring exposed timber.

CLADDING

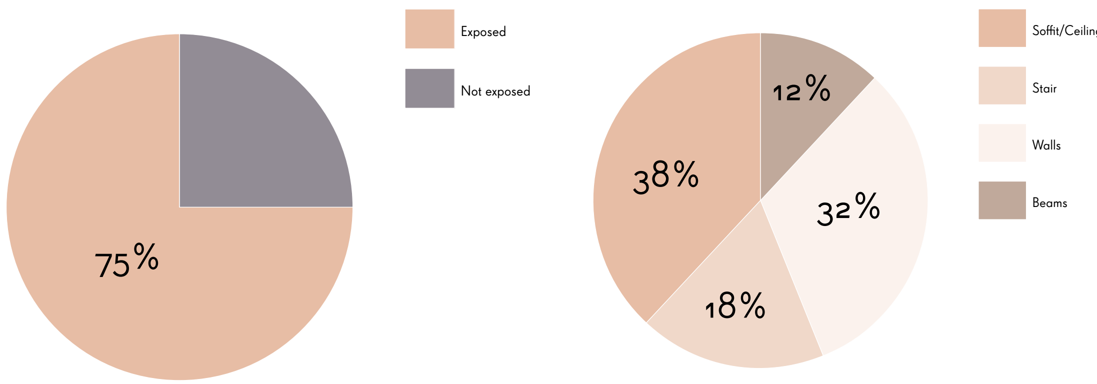
A solid timber structure is just as versatile as a steel or concrete solution and can be clad in any material with the same considerations for water ingress and longevity. The key requirement is to include a cavity to ventilate the panels and keep the timber dry.

In many cases fixing to CLT is more straightforward than fixing to concrete and steel due to the finer tolerances and the ease of working. However, it should be recognized that the fixings used for brick ties, cladding rails and framing systems tend to be bespoke for timber and should be specified as such. Additionally, fixing zones should be established to avoid screwing into the end grain of panels.[4]

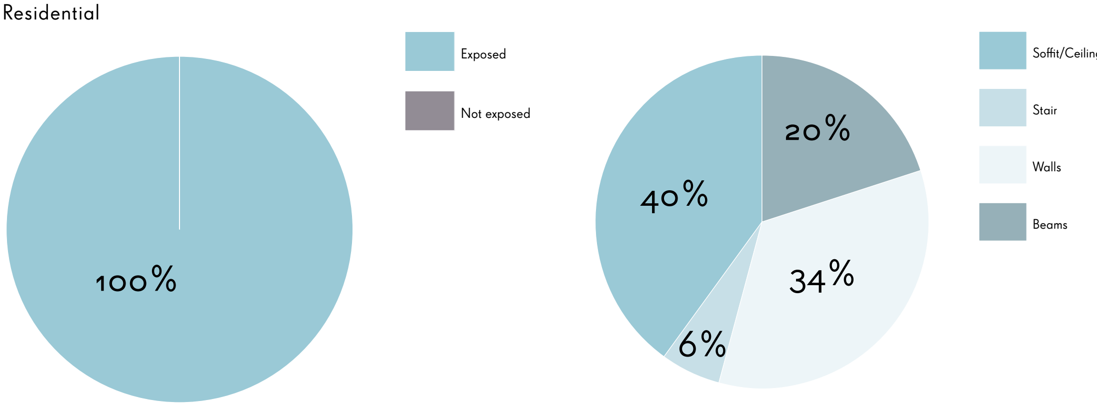
The use of a masonry outer leaf such as brick or rendered block, can have the benefit of further stabilizing the structure by increasing the dead load. Although for larger scale buildings, the weight of brickwork hanging off the structure can be considerable and may impact on the overall design and the volume of timber needed.[5]



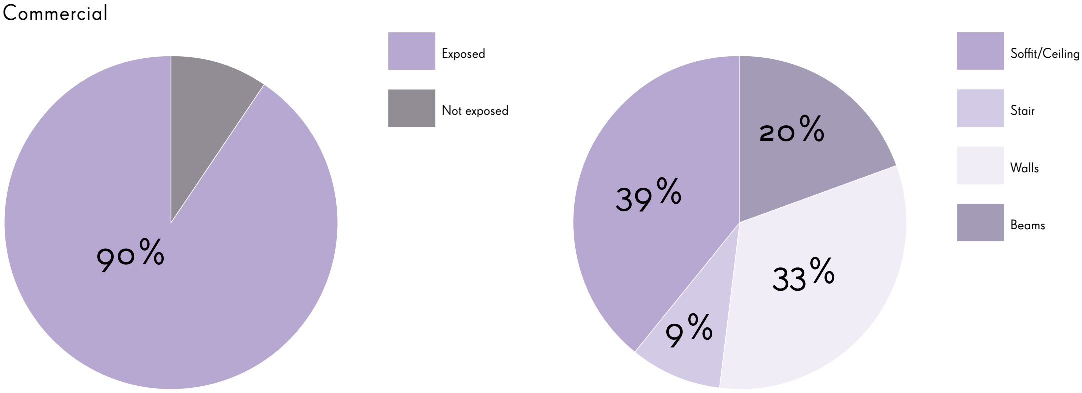
Education



Residential



Commercial



Public & Civic

Given the primary drivers for using CLT tend to be the embodied carbon and light weight, there is a tendency to use cladding solutions that match these principles. For example at Whitmore Road (pg.192-193) a British Sweet Chestnut cladding echoes the core structural material. Of the case studies, 26 use a render or low density cladding board and 47 incorporate solid timber external cladding.

WATER

The softwood typically used for CLT is factory dried to a moisture content of 12% (+/- 2%)[6] at which level it will not deteriorate. However, where CLT is exposed to sustained high levels of moisture (over 20% moisture content), decay is likely to occur.[7] The probability of decay also being influenced by the temperature and oxygen supply. It is therefore imperative to ensure that CLT structures are designed, constructed and maintained to ensure that contact with water is minimized and that any moisture is not trapped.

In order to avoid inherent defects or installation errors, it is essential that the designers and contractors, including follow-on trades, are made aware of the specific nature and vulnerabilities of CLT. Inclusion of a specification giving detail on mitigating weather issues is advisable as part of the installation contract.

The interface with the ground is of key importance and in most instances it is advisable to lift the CLT from external ground level by a minimum of 6 inches (150mm). While it is possible to design with the CLT sitting straight on the ground level slab, any failure in waterproofing or in workmanship can lead to issues with the base of the panel. In detailing the connection between the timber and the substructure particular attention should be given to ensure that water is not able to collect at the base.

In many cases the CLT is built on a podium level constructed from concrete. As well as lifting the timber off the ground, this concrete podium can assist in transferring loads across the ground floor where the program, particularly in residential developments, requires a very different internal arrangement to the floors above, due to a difference in use.

In general, the CLT structure should be designed to be warm - that is, any external elements should be outside of the insulation layer. This ensures that the dew point does not occur within the material.

For internal wet areas, such as bathrooms, additional consideration should be given as to how to avoid water traps where minor leaks could create sustained moisture build-up over time.

VENTILATING THE TIMBER

CLT is designed for use in dry, internal environments only - it is only suitable for external use where protected in a thermal envelope and kept dry.[8]

When designing for airtightness, it is essential to ensure that all elements of the timber structure are able to breathe to allow them to dry out should any moisture get into the panels through rain during construction, humidity variations or leakage of services.

Ventilation is also advisable above roof panels and completely flat roofs should be detailed carefully to avoid surface water pooling and vulnerability from failures.

If the timber is in contact with free-flowing air it will tend to revert to the ambient moisture content. If the timber itself forms the airtightness line then, assuming there is a ventilated cavity, this is not an issue as the panels are exposed to fresh air to absorb the moisture.

If a membrane is used it is vital that a vapor permeable membrane is specified to prevent locking in moisture. In traditional construction a vapor control layer to the internal face forms the air tightness line whilst with CLT construction this is not typically required as the panels can form the air tightness line when taped externally. This is supported by the large number of respondents that indicated the air tightness line to be on the outer face of the CLT.

INFESTATION

CLT is generally considered to be invulnerable to insect attack, as noted within European standard DIN 68800-2 (6.3b), which states that "... the exclusive use of glued laminated timber, cross laminated timber, artificially dried building timber or wood-based panels with a moisture content u>20% in service is sufficient to avoid structural damage by insects".

Many suppliers provide panels with a treatment to resist against a wide range of potential species. However, consideration should always be given to the suitability and robustness of these applied treatments where local conditions, or legislation, may necessitate a specific solution.

PROCESS

FINALIZING THE DESIGN

In comparison with more traditional forms of construction, the procurement of CLT requires a greater level of coordination earlier in the design process including the full coordination of the mechanical and electrical services. This upfront coordination means that all openings can be cut in the factory, avoiding the need to make changes to panels on site. While amendments on site are possible, this can be costly, may reduce the benefits of factory precision and can require re-calculation of the structure.[9]

Prefabrication of panels in the factory offers accuracy and quality, optimizing material use whilst vastly reducing site waste. The ability to accurately route various joints, profiles and openings enables easy assembly of complex forms and sufficient certainty of structural opening dimensions to pre-order elements such as windows, doors and grilles.

To ensure sufficient coordination, it is important to allow both time and budget for a front-loaded design period which is likely to require a larger draw down of fees for architects, engineers and consultants early in the program. Furthermore, capital input can also be required earlier in the project in order to purchase the CLT package and other prefabricated elements.

Typicaly for the UK market, the final coordinated drawings and structural model need to be completed 6-12 weeks before the first panels are scheduled to arrive on site. Within this lead-in period the first 3-6 weeks will allow for checking and production of manufacturing drawings, with the latter 3-6 weeks set aside for production and delivery.[10] The length of lead-in time can vary due to the complexity of the project, the supplier and the time of year.

Accounting for this, the site mobilization and ground works can be completed within the lead-in period and be ready for the arrival of the first panels.

BUILDING INFORMATION MODELLING

With the increased uptake of Building Information Modelling (BIM), the typical design workflow on projects is changing, with design freezes occurring in earlier stages of the work. This is primarily a result of the increased collaborative design work, with the principal disciplines working on a common model allowing the integration of structure and services with the architecture as the design develops. This 'front-loading' of design suits the procurement of CLT very well as it is advantageous to be able to sign off the superstructure design to allow for the lead-in for fabrication and to maximize the program advantages.

Through the use of a shared BIM model by the various consultants involved, the coordination of all openings required is made considerably more straightforward, enabling the completion of the fully coordinated design in time for the panel production.

A number of CLT producers are in the process of making their building systems available as digital objects for download. These will generally include wall and floor components as well as the wall and floor structural panels.

The current process of procuring panels does not yet take full advantage of the possibilities that further BIM levels offer. With the panels being cut by CNC (computer numerical control) routers there is no technical reason that the model created by the design team cannot be used as the basis for the fabrication.

In practice, however, the CLT manufacturer will normally produce their own model within the CNC software, taking account of the panelization and optimizing to minimize waste.

COMPETITIVE TENDERING

Currently, there are no universal parameters for CLT panels, with each manufacturer supplying a slightly different product range. This can create issues for competitive tendering as schemes should be designed to suit a particular manufacturer's panel sizes to optimize the system.

To ensure the best price is obtained it is beneficial to work with an experienced structural engineer with specific knowledge of CLT construction and an understanding of the various products available. This knowledge can inform the production of an outline design based on structural parameters, which will enable multiple suppliers to bid for the work.

At tender it is common for each manufacturer to propose two quotes: the first is based on the generic design received, the second on an optimized scheme if the supplier can identify possible further efficiencies.

The successful tenderer can then be identified to the principal contractor and allowances for program and cost made within the main contract. Once appointed under the main contract the CLT provider works with the construction team to refine the design and finalize connection details.

This approach can add an additional step to the tender process but it ensures that competitive prices are received by the client and should avoid any redesign that can be required should a different CLT supplier be appointed to construct the scheme.

On the Dalston Works scheme (pg. 228-229), the engineer, Ramboll, produced a tender information set that identified the characteristics of each panel based on the specific systems of the three main manufacturers. Color coded drawings were issued with a key to identify the panel type of every wall and floor panel. To our knowledge, this was the first time that a CLT structure was able to be competitively tendered on a full structural design.

Endnotes

1 Chris Wise., What if everything we did was wrong? Building Online, 2010 <http://www.building.co.uk/what-if-everything-we-did-was-wrong?/5000493.article> [accessed 20 August 2017].

2 KLH UK, Frequently Asked Questions, 2017 <http://www.klhuk.com/media/11553/frequently%20asked%20questions_05042011_1.pdf> [accessed 10 July 2017].

3 Questionnaire from Liam Dewar, Eurban, 15 September 2017.

4 Gavin White, Ramboll, Interview by A.Thistleton & R.Sawcer, London, 8 September 2017, Waugh Thistleton Offices.

5 Gavin White, Ramboll, Interview by A.Thistleton & R.Sawcer, London, 8 September 2017, Waugh Thistleton Offices.

6 Questionnaire from Kay Hartmann, KLH UK, 11 September 2017.

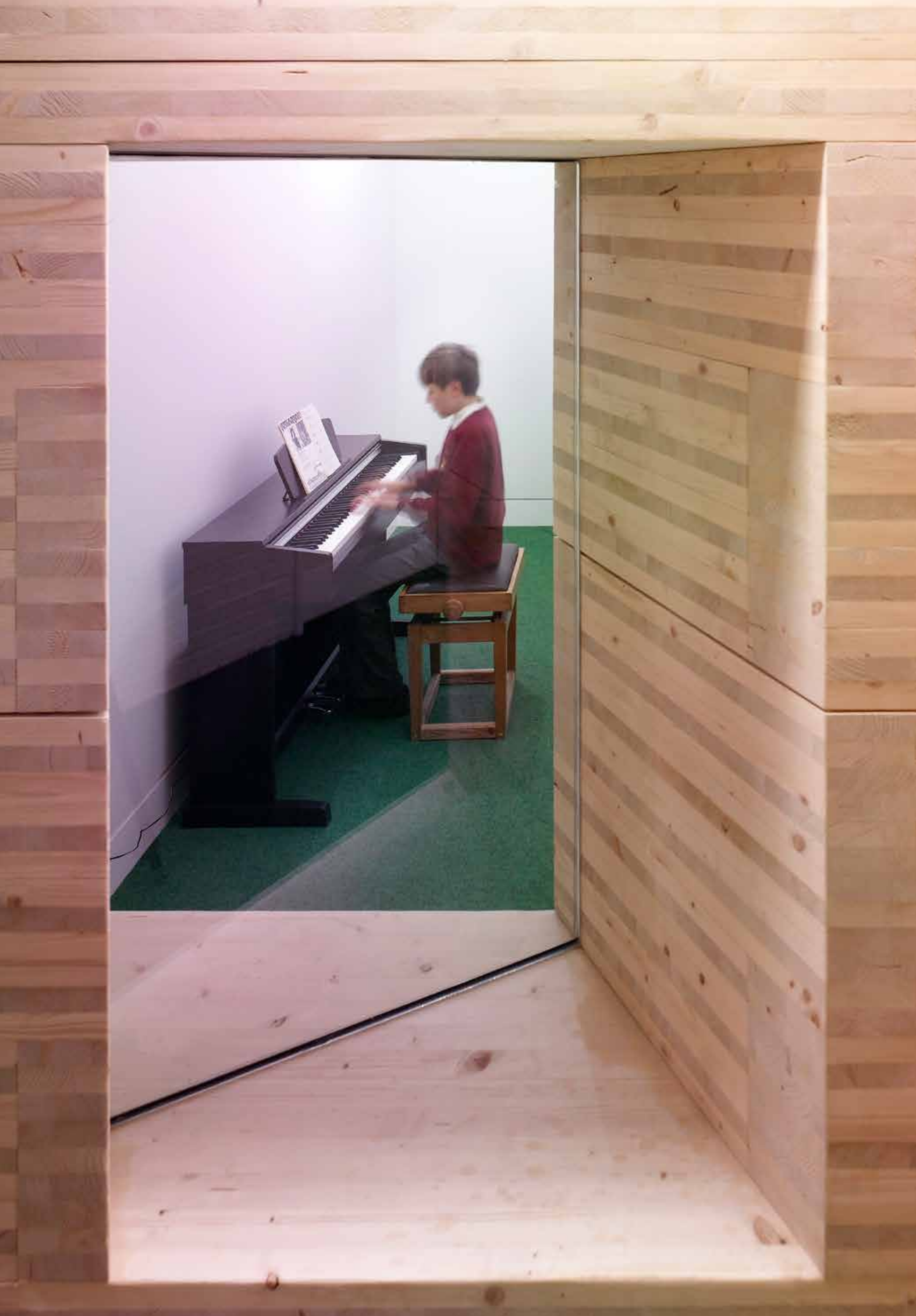
7 Questionnaire from Gareth Mason, Stora Enso, 8 September 2017.

8 KLH UK, *Technical Characteristics,* 2017 <http://www.klhuk.com/media/29233/technical%20characteristics.pdf> [accessed 10 September 2017].

Stora Enso, Technical Brochure, 2017 < http://www.clt.info/wp-content/uploads/2017/09/Technical-brochure-CLT-EN.pdf> [accessed 10 September 2017].

9 Ian Brooks, Kier Eastern, Interview by R.Sawcer, 12 September 2017, Telephone.

10 Questionnaire from Gareth Mason, Stora Enso, 8 September 2017. KLH UK, Frequently Asked Questions, 2017.



MATERIAL PERFORMANCE

Being a wood product, cross-laminated timber is often associated with timber frame construction, however the performance characteristics of CLT are very different.

As a panelized form of construction, CLT has more in common with prefabricated concrete panel construction, albeit with improved workability, flexibility and weight.

While there have been a wide range of tests on the behavior of CLT in fire and the thermal and acoustic characteristics, much of the performance data of a material comes from in-use testing. Clearly, as a relative newcomer to construction, there are fewer precedent CLT buildings however this is changing rapidly as more schemes are completed and the industry as a whole is working to accelerate testing to be able to best inform designers.

Image: Hayes Primary School, Hayhurst and Co. © Kilian O'Sullivan

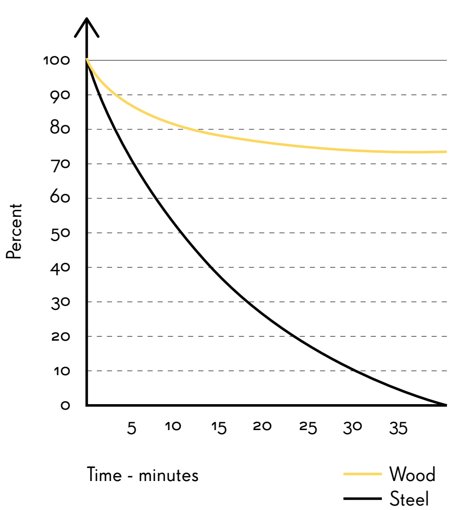
FIRE

As wood is combustible it leads to an inevitable concern about the fire performance of timber buildings. However it is important to understand that all materials have their limitations when exposed to a fire. No construction method or material is immune to fire so this should not be a constraint particular to building in timber, but an important design parameter for all construction.

While CLT is now well established and there is significant standard test data on which to base fire mitigation design, continuing research is required to ensure that these assessment methods reflect the risks posed by engineered timber.[1]

In many cases, specialist fire engineering is essential to minimize risk and ensure the structure and linings present an appropriate solution. The key principles for design are to devise the appropriate fire strategy at the early stages, clearly establish the responsibility for who implements each part and to make sure that the construction stages are included.

WOOD VS STEEL:LOSS OF STRENGTH IN FIRE



LEGISLATION

Until the early twentieth century most UK fire legislation was made in response to catastrophic events that resulted in substantial loss of life. Typically 'stable door' legislation is aimed to prevent recurrence of such events and is therefore targeted at the conditions that led to the incident.[2] In the UK, for example, the Great Fire of London, in 1666, resulted in a number of statutes relating to building materials, architectural form and the separation between buildings. These and much of the legislation over the next 200 years related to prevention of the ignition and subsequent spreading of fires.[3]

In the USA, the Great Chicago Fire of 1871 led to sweeping reforms both statewide and across the continent and subsequent fires have led to further updates in legislation leading to the Federal Fire Prevention and Control Act of 1974.[4]

To a large extent, local fire codes across the world tend to be highly prescriptive, with limits to the use of combustible materials, such as timber, for building structures over a certain height or for elements such as stairs.

In contrast the UK building regulations, part B of which covers fire, set a series of requirements that must be met. This allows a certain degree of interpretation and a system will be approved if it can be demonstrated to meet the objectives of the regulations. This ability to assess the site, building system performance and occupancy conditions on a per project basis allowed the first tall timber buildings to be constructed without a change to the legislation and has contributed to the rapid expansion of CLT use in the UK.

As CLT use develops and taller structures become more widespread, more codes are being adapted to accommodate modern engineered timber although this is a slow process and restrictions still apply in many locations.

DEALING WITH FIRE AUTHORITIES

As long as CLT is still perceived as a novel material, early engagement with local fire authorities is strongly recommended.

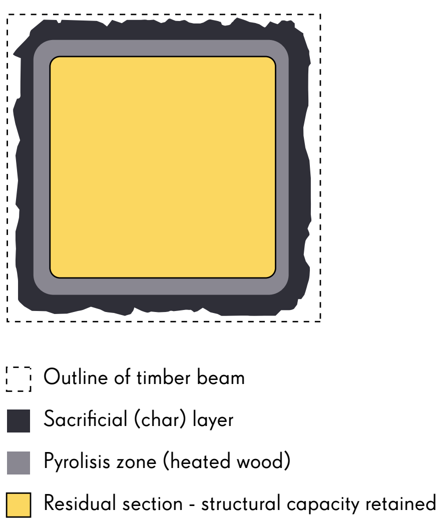
In most situations, those who enforce fire codes have been front line fire fighters so they have an implicit understanding of how fire behaves. When a fire officer is given an opportunity to view a CLT structure under construction, many concerns are quickly allayed.

At Dalston Works (pg.228-229), initial discussions with fire officers were positive and the principle of the structural design and fire protection was accepted. However as more detail of the project was submitted and the fire authority carried out further assessment, they raised a number of concerns, specifically in respect of smoke temperature. Detailed smoke modelling was subsequently carried out, which demonstrated that additional fire protection within elevator shafts was not required as the maximum temperatures that would occur would not cause charring or ignition of the timber.

FLAMMABILITY / PYROLYSIS

The energy required to ignite a large timber panel is significantly higher than that required for a plank or stud meaning that fires are unlikely to start with the CLT.

The behavior of CLT is that it will begin to char once it is exposed to temperatures of 570°F (300°C) and above.[5] As the face of the timber chars, the zone of wood inside is heated, known as the pyrolysis zone in which the wood starts to undergo thermal decomposition. A 'zero strength layer' of heated wood exists behind the char which has lost any structural performance. Beyond this the wood is unaffected and will function structurally as normal.



Typical spruce CLT panels char at a average rate of around ¼ inch in ten minutes (0.7mm/min), with the initial rate on each layer exceeding this temporarily.[6] By oversizing elements to allow for a sacrificial zone, the relevant fire performance can be met. The structural stability can then be maintained through no additional coatings or covers. If several layers of the CLT panel are predicted to burn off within the fire integrity period then a modified charring rate is used to allow for the increase in charring rate when burning between the layers, at which time the initial layer may fall off or catch alight, known as de-lamination. It is, however, preferable to deal with this by using thicker boards for the outermost layers that are sufficient for the char of the entire fire integrity period.

Beyond this, additional fire performance is achieved through encapsulation, that is by adding fire protective barriers such as plasterboard or fire-board. Typically, a high degree of fire separation, such as 90 minutes or above, will be achieved through a combination of both sacrificial timber and fire-board.[7] When using this approach, it is essential that heat degradation of the timber behind the board is considered and calculated as the CLT will initially char at a higher rate once the board fails.

FIRE PERFORMANCE

The timber was said to have contributed to the building's fire performance in 60 of our 100 schemes.

It is noteworthy that several of the responses indicated the timber's performance could have further contributed to the fire integrity had the consulting fire engineer allowed the fire performance to be provided through a combination of partial encapsulation and partial charring.

Of the 100 schemes, 65 employed a fire engineer to advise on the best approach to fire protection of the structure. The proportion was higher for large commercial and residential schemes. However, a similar percentage of large scale building projects would involve a fire engineer within the construction industry as a whole. The results of our study, therefore, show that building in timber does not appear to have increased the involvement of these specialists.

SPREAD OF FLAME

Where the timber structure is exposed, designers need to consider the potential for fire to spread rapidly by tracking across large flammable surfaces. Untreated, CLT is defined as class D-s2,d0 (Class III surface lining) under European regulations, as it produces low levels of smoke and no flaming droplets despite being a combustible material.[8]

A number of chemical retardants are commonly available to reduce or prevent the spread of flame, however these may have a wider environmental impact both in their production and in limiting the timber's re-use at the end of the buildings life. They also need to be maintained or reapplied every few years.

Of the schemes with exposed timber 84% required treatment for spread of flames, of those that didn't most were small low-rise schemes. This indicates the importance of escape times, travel distances and the number of occupants as required by the UK building regulations.

CONNECTIONS

The connections between the timber panels are of critical consideration. While the timber panels themselves may perform well under fire, if the connections fail then the stability of the building will be quickly undermined.

Most connectors are fabricated from steel and the performance of steel in high temperatures deteriorates. Typically the connectors will be protected within fire board as part of the overall encapsulation strategy. If the connectors are visible, detailing of the interface between the connector, the fixing and the CLT should be considered to prevent heat transmission into the timber which could cause adverse charring and failure of the fixing.

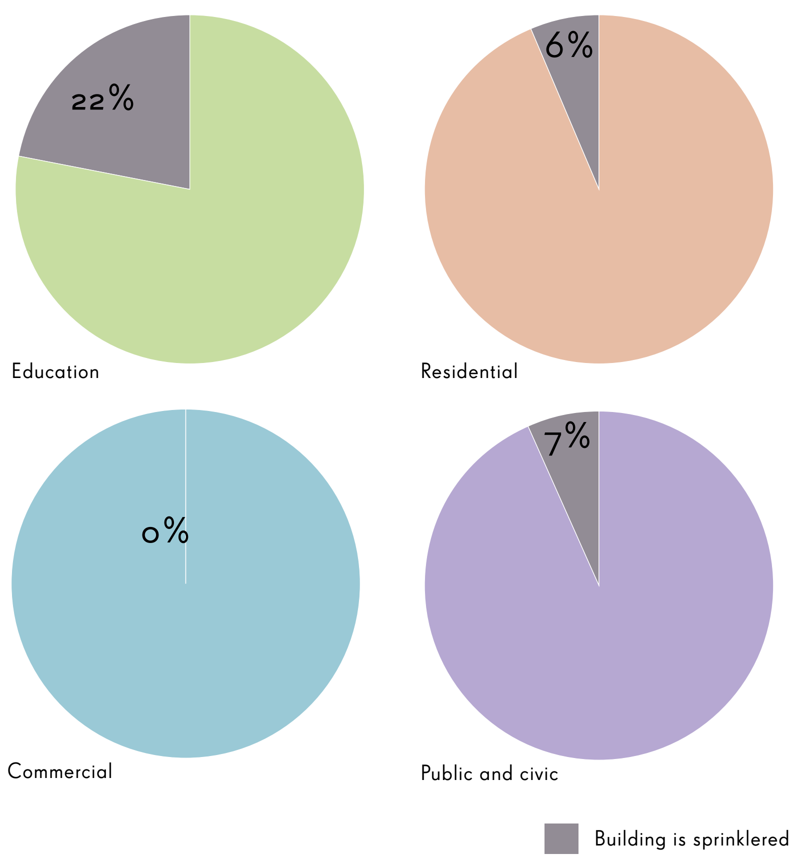
SPRINKLERS AND OTHER SUPPRESSIVE SYSTEMS

The International Fire Sprinkler Association (IFSA) asserts that automatic fire sprinkler systems are the most effective fire protection measure available, as to date there has never been multiple loss of life due to a fire that has developed in a building with a properly designed, installed and maintained sprinkler system.[9]

However, it is important to note that no suppression system is guaranteed to function all of the time and therefore designs must consider the potential that a sprinkler system could malfunction or be out of service for maintenance.[10] Equally it must be recognized that sprinklers will only slow down the rate of fire growth and are not intended to extinguish it. Sprinklers should be considered as an additional measure following consideration of escape distances, sufficient structural performance in the event of charring or encapsulation and spread of flame.

Sprinklers were only used in 10 of the schemes, of which 7 were educational. This is unsurprising as fire strategies for schools are usually very thorough regardless of the structural material due to the need to evacuate such a large number of vulnerable children. It appears, therefore, that sprinklers do not seem to have been an essential mitigating addition for engineered timber structures.

It is interesting to note that for the Hastings Pier scheme (pg.304-305), by dRMM, sprinklers were incorporated due to the location of the building (being in the middle of a pier, 500ft (150m) from the shore) as opposed to the use of a timber structural system.[11]



THERMAL PERFORMANCE

CONDUCTIVITY

Timber has a low thermal conductivity, which reduces the risk of thermal bridging, which is a common concern in steel or concrete buildings. This can simplify detailing and assist with structural design. For example, in some cases an internal floor slab can be continued outside to form a balcony without a thermal break.

Timber also has a relatively high thermal storage capacity, given it's density, which ensures it not only insulates against cold ingress in winter months but can protect against summertime overheating. Timber naturally regulates heat and moisture, creating high quality internal environments, especially where the surface is exposed.

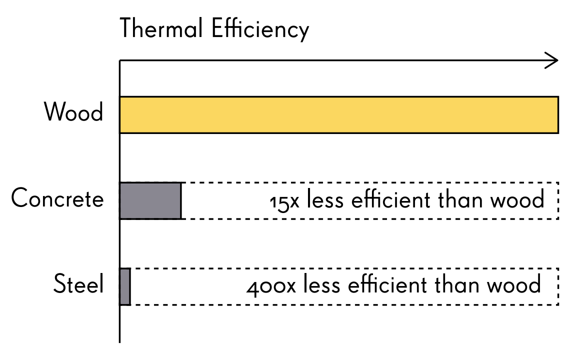
The low thermal conductivity of timber also allows a reduction in the quantity of insulation. This can help reduce quantities of high-embodied carbon materials, however more essential to ensuring excellent thermal performance is good detailing - building in CLT does not guarantee a thermally efficient building.

The standard method of calculating thermal transmission is via R-values, measured in $ft^2{}^\circ Fh/Btu$.[12] Timber elements give low psi values, a factor used in thermal bridging calculations. This helps within SAP calculations to reduce the R-value needed to achieve specific targets aimed for in the UK energy accreditation system BREEAM and other codes.

Under many certification regimes, including BREEAM, credits are given for exceeding the base thermal performance. Higher levels of thermal performance were targeted in 27 projects.

MASS

If exposed, the thermal mass of traditional concrete and masonry structures is excellent at regulating temperature change and reducing the heating or cooling loads through passive thermal storage. CLT panels are not as thermally massive as concrete so they are less able to perform this role, however there are alternatives to creating thermal mass. At the Woodland Trust Headquarters (pg.240-241), concrete 'radiators' were bolted to the underside of the CLT panels to work structurally with the timber and to provide the additional thermal mass required for night cooling. Where the structural material is not exposed, its ability to perform this function is greatly reduced in which case the comparative performance of CLT is not as significant. The use of 'phase change' materials can also replicate the beneficial effects of thermal mass.



© Yugon Kim

Notwithstanding this, changes in the internal temperature of timber lag behind changes in the external temperature. This 'phase shift delay' that occurs naturally helps reduce summertime overheating from high external temperatures and can also aid in levelling out daytime and night time temperatures by transmitting heat from the middle of the day through the night.

DYNAMIC RESPONSE

Standard R-values assume a steady-state flow of heat through the element and do not take into account the thermal buffering of the material through thermal mass. More research is necessary to establish how timber performs against other materials such as masonry.

By using a static model, the timber's performance is often underestimated resulting in most CLT structures outperforming their design parameters.

If the true performance of timber could be accurately calculated, this could be taken into account, reducing the volumes of additional insulation products needed along with reduced cost and thinner walls. While monitoring the performance of timber based façade systems to obtain data would assist in refining the understanding of their behavior, most efficiency accreditations are based on calculations only, which diminishes the incentive to monitor completed buildings.

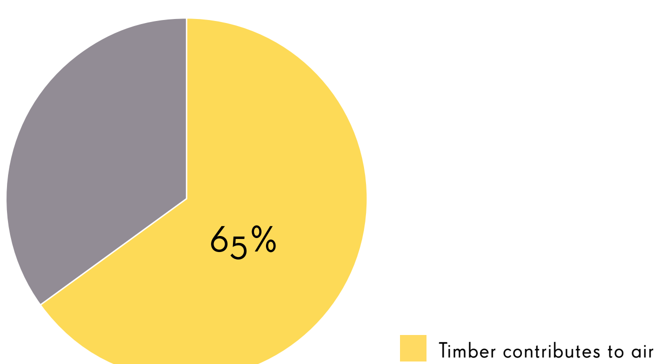
As CLT is a solid material there is no room within its structural depth for the use of conventional infill insulation to supplement its performance. As a result of this, the increased performance offered by CLT is not necessarily reflected in reduced wall thickness.

AIR TIGHTNESS AND ACCURACY

Another advantage of CLT in terms of thermal performance is the high level of airtightness that can be achieved. The accurate cutting means the panels fit together well, with tape applied at the connections between panels and penetrations all sealed appropriately. Most panels can be used to create an airtightness layer to the building envelope.[13]

This is reflected in the 65 schemes in which the timber was noted as contributing to the buildings air tightness.

Many schemes exceeded the airtightness targets, some by a considerable margin. Of the schemes investigated, 46 used tape alone to achieve airtightness, indicating how many designs are taking advantage of this additional performance, while only 27 used a membrane in addition to the panels. Accuracy of prefabrication was a primary factor in choosing a CLT structure in 15 of the schemes.



ACOUSTICS

Most acoustic design relies on data from a multitude of similar historical installations. Thus, there is a wealth of knowledge of the performance of traditional construction details. This allows acoustic engineers to design efficiently and be certain that their designs will perform at the level required. The lack of data for CLT significantly impedes this process.[14] However, we found that in post completion testing, the acoustic performance of many of the schemes exceeded the design levels, often by a considerable margin.

Making the walls from solid timber as opposed to the metal or timber stud walls found in concrete frame construction, can offer significant improvements to the acoustic performance.

For a typical internal wall of an apartment, a CLT wall will offer noticeable improvements over a stud framed counterpart. For acoustic separation between apartments, it is possible to create high levels of insulation by using two panels seperated by an air gap, however, it is materially more efficient to use one or two layers of plaster boarding on either side of the CLT, mounted on acoustically insulating brackets.

When designing in CLT, flanking sound is an important consideration. While the density of CLT is an asset both thermally and structurally, the continuity between walls and floors in a CLT structure provides acoustic pathways that could transmit sound over large distances across a building if not insulated. For this reason, acoustic breaks should be used to prevent the transmission.[15] These can be layers of compressible insulating material in the joints between walls and floors, or adjacent floor slabs.

An alternative or complementary approach is to prevent the sound getting into the structure through acoustic build-ups between the habitable spaces and the structure. For walls, this is achieved through using multiple layers of plasterboard, separated from the primary structure.

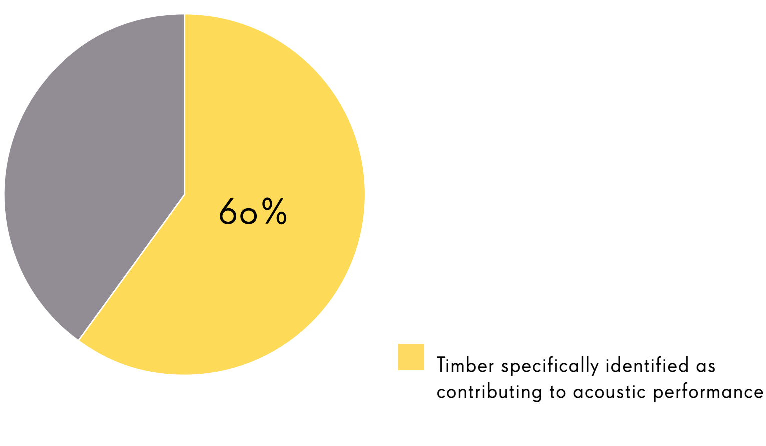
Impact sound on floor slabs should also be considered. A common solution is to include a layer of concrete screed above a resilient mat laid onto the CLT slab.[16] This can also be a good vehicle for underfloor heating and can help with providing additional thermal mass.

As with any acoustic design, the performance relies on the correct installation. The solidity of CLT construction and the workability of the material assist in limiting the scope for failure of acoustic measures.

As more buildings are completed and tested, this will allow acoustic engineers to design more knowledgeably with CLT. The industry would also benefit from investment in prototype testing to build up the amount of data.[17]

Of the 100 projects, consultants from 60 stated specifically that the timber contributed to the acoustic performance.

The usual thickness of CLT panels across the 100 schemes was 4½ inches (110mm) for walls and 6¼ inches (160mm) for floors. Based on the typical approaches to detailing and typical details across the schemes that we have looked at most added some form of acoustic insulation rather than increase the thickness of the CLT for the acoustic performance. This was certainly the case within all the residential buildings; largely a reflection of the more stringent acoustic requirement in residential buildings.



VIBRATION

CLT offers benefits in terms of strength to weight ratio, but the relatively lightweight nature and stiffness of the material can make it more susceptible to vibration.

Vibration in structure is classified according to the response factor and is based on human perception. The principal source of vibration is footfall with acceptable levels depending on the use of the space; for example within a residential development these might be relatively high within corridors with a far lower requirement from bedrooms.[18]

Other considerations are the size of the span or the use - for example a gym would generate a significantly increased frequency and scale of impact.

Vibration is dealt with through increasing the mass of the slab and adding dampening at junctions.

Typically two solutions are found over the CLT floor slab. These are a lightweight concrete screed or other mass laid on an acoustic insulation and underlay above the slab, or a "dry" solution with chipboards on battens sitting on acoustic cradles with dry insulation between.

Acoustic linings and insulation to ceilings and walls will also help the situation but are more effective for airborne sound than vibration.

The additional mass of the floor build-up will increase the inertia of the floor, which is more difficult to excite by foot-fall. The added materials also distribute the load over a wider area of the CLT, and provide additional damping by the interaction of the CLT panels and build-up.

Another key measure to prevent transmission between apartments is to have discontinuous floor to wall panel junctions, avoiding continuous spans over party walls.

Endnotes

1 Rory Hadden, University of Edinburgh / The BRE Centre for Fire Safety Engieering, interview by A.Thistleton & R.Sawcer, London, 27 September 2017, Waugh Thistleton Offices.

2 Fire Safety Advice Centre, *History of Fire Safety Legislation,* 2011. <https://www.firesafe.org.uk/history-of-fire-safety-legislation/> [accessed 15 September 2017].

3 Fire Net, *History of Fire Safety*, 2009 <http://www.fire.org.uk/history-of-fire-safety.html> [accessed 15 September 2017].

4 Fire Files Digital Library, *National Fire Prevention and Control Administration,* 2017 <https://fire.omeka.net/exhibits/show/nfpca> [accessed 20 November 2017].

5 Danny James Hopkin, Loughborough University Centre for Innovative and Collaborative Engineering, *The Fire Performance of Engineered Timber Products and Systems,* 2011 <https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/8981/1/Thesis-2011-Hopkin.pdf> [accessed 18 September 2017].

6 KLH UK, Frequently Asked Questions, 2017 <http://www.klhuk.com/media/11553/frequently%20asked%20questions_05042011_1.pdf> [accessed 10 July 2017].

7 Gavin White, Ramboll, Interview by A.Thistleton & R.Sawcer, London, 8 September 2017, Waugh Thistleton Offices.

8 Stora Enso, Cross Laminated Timber Fire Protection, 2013 <https://www.trada.co.uk/media/5878/13_04_30_clt_documentation_on_fire_protection.pdf> [accessed 20 July 2017].

9 Chief Fire Officers Association, *Business Case for Sprinklers,* (Staffordshire, CFOA Publications, 2013) p.2.

10 Rory Hadden, University of Edinburgh / The BRE Centre for Fire Safety Engieering, interview by A.Thistleton & R.Sawcer, London, 27 September 2017, Waugh Thistleton Offices.

11 Peter Wheeler, Hastings Pier Charity, Interview by R.Sawcer, 19 September 2017, Telephone.

12 Understand Building Construction, Thermal Insulation Explained, 2017 <http://www.understandconstruction.com/insulation.html> [accessed 20 November 2017].

13 KLH UK, Frequently Asked Questions, 2017 <http://www.klhuk.com/media/11553/frequently%20asked%20questions_05042011_1.pdf> [accessed 10 July 2017].

14 Simon Taylor, Ramboll, interview by A.Thistleton & R.Sawcer, London, 5 September 2017, Waugh Thistleton Offices.

15 Simon Taylor, Ramboll, interview by A.Thistleton & R.Sawcer, London, 5 September 2017, Waugh Thistleton Offices.

16 Gavin White, Ramboll, Interview by A.Thistleton & R.Sawcer, London, 8 September 2017, Waugh Thistleton Offices.

17 Simon Taylor, Ramboll, interview by A.Thistleton & R.Sawcer, London, 5 September 2017, Waugh Thistleton Offices.

18 Simon Taylor, Ramboll, interview by A.Thistleton & R.Sawcer, London, 5 September 2017, Waugh Thistleton Offices.

SITE FACTORS

While there are many benefits on site from using CLT, engaging with the differences in process at an early stage is the best way to maximize these. While many of the schemes reported program advantages as a key driver for the selection of CLT, there has not been any comprehensive guidance for ensuring that all the potential benefits are realized.

It is also essential to ensure that those tasked with constructing the building fully understand the differences in process and material characteristics with CLT.

Many common mistakes that have been reported in the course of this study could be avoided with more comprehensive briefing of the construction team at the outset of site operations.

With CLT entering the mainstream and procurement of the material becoming standardized, more contractors are gaining experience enabling the improvements to build speed and quality to be more readily accomplished.

Image: Wildernesse Restaurant, Duggan Morris Architects © Mark Hadden

OPTIMIZATION

SEQUENCING

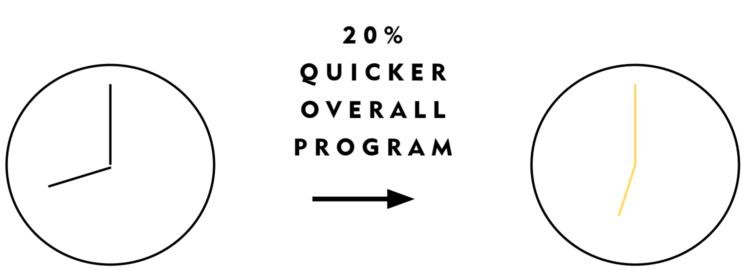
In order to take the best advantage of the potential time savings, the programming of the various packages and subcontractors on site has to be approached in a non-conventional manner. A main contractor with experience building with CLT will understand how CLT impacts follow-on trades. They can therefore maximize this saving, instructing subcontractors to ensure they are mobilized in good time. This scheduling should not be based on experience of traditional builds.[1]

GROUND WORKS

The lighter weight of the CLT frame generally requires reduced or shallower foundations than a traditional building. This typically leads to a shorter program for ground works, involving less excavation, reduced piling and concrete volumes. These time savings should be factored into the site delivery schedule for the CLT.

INSTALLATION

The direct install speed of the structure itself is faster than conventional construction methods. Delivered just-in-time, the panels are often directly craned from the truck and fixed into place using hand held tools. The panels are immediately ready for the subsequent floors to be built on top,



requiring no scaffolding for erection and no formwork prior to installation. In comparison reinforced concrete requires setting out, formwork, laying and tying of reinforcement, pouring, curing and striking of the formwork before the next floor can be started. As a result concrete frames can be erected at a rate of around 5,400 ft^2 ($500m^2$) per week,[2] whereas CLT is typically installed around 25-45% faster.[3]

As CLT forms full walls rather than just a structural frame the period required for the secondary structure is also reduced.

As a result of these factors and others, the number of operatives required for erection is substantially reduced.

PROGRAM OVERLAP

Follow-on trades can begin work on a CLT structure as assembly of the frame continues. This program overlap can significantly shorten the critical path, and is where the greatest program savings can be achieved. Maximizing this opportunity relies on the sequencing arrangement and ensuring the relevant subcontractors are ready and on site to begin earlier than would ordinarily be expected.

BACK-TO-BACK PROCESSES

The prefabrication of CLT panels in a factory and the high precision CNC routing/cutting make for an extremely accurate product, with typical tolerances of +/- 1/8 inch (+/- 3mm).[4] This precision allows for the pre-ordering of other factory made products, such as windows and doors. By using these back-to-back processes, fittings can also be delivered just-in-time, potentially reducing the construction period further.

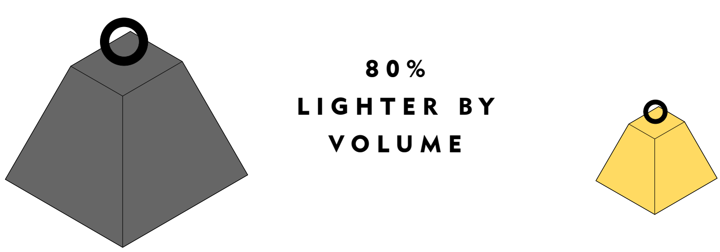
MATERIAL SAVINGS

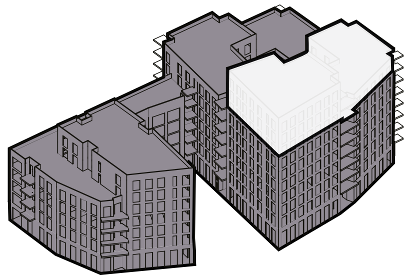
LIGHTWEIGHT

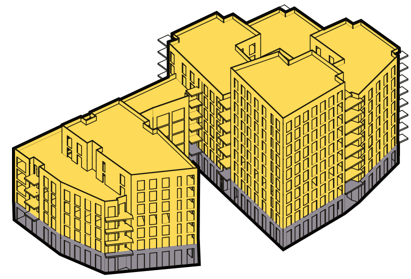
Although CLT is a solid structural material, with a similar structural performance to concrete, it is comparatively lightweight, weighing approximately 35lbs/ft^3 (480-500kg/m^3),[5] which is around 20% of the weight of the same volume of concrete.[6]

This reduced weight can enable construction on sites with ground constraints, or facilitate an increased accommodation provision where weight is an issue. Similarly, it can enable construction on rooftops and even within existing structures. At Dalston Works (pg.228-229), a restriction on piling due to transit tunnels beneath the site required a raft foundation. For a concrete frame building, a maximum of 86 flats could be built, however in CLT the same loading would be imposed by 121 flats - a significant advantage for the developer.

While the requirement for foundations depends on both the superstructure loading and the ground condition, the lower density of a CLT frame tends to result in a saving in groundworks and reduction in foundations as compared to traditional builds. The related cost saving is generally in the region of 10%. Savings of up to 20% can be achieved if ground conditions are favorable and a mobile crane can be used.







86 FLATS **121 FLATS**

35 additional apartments were possible at Dalston Works as a result of the weight savings from using CLT.

PRIMARY STRUCTURE

In most cases, the floor build-ups for a concrete frame structure are greater than those that can be achieved in CLT. This can reduce building heights, leading to savings in external cladding, with no loss of internal height. Where height limits are imposed by local building codes or fire protection, there are situations where the cumulative gain can lead to being able to include an additional storey.

EXPOSING CLT

While exposing CLT can reduce the cost of applying finishes, a more expensive, higher visual grade CLT is often chosen. Typically most manufacturers offer various grades: Non-Visual Quality (NVQ), Industrial-Visual Quality (IVQ) and Visual Quality (VQ) grades, with the cost rising with the level of finish.

In some instances the intermediate IVQ can be used as an exposed surface minimizing the cost increase. The step up to IVQ from NVQ typically increases the cost of a 4 inch (100mm) wall panel by 18%, whilst for VQ this increase is around 35%.

As the increased cost for an upgrade in visual finish is usually consistent, for a thicker panel of 6 inches (160mm) the cost increase is less, at 12% for IVQ and 22% for VQ. In addition, more careful handling of panels and quicker erection can be required where a higher visual finish is desired, this can add additional expense.[7]

MITIGATING COMMON ISSUES

DELAYS

Delays are common in construction. The UK Construction Key Performance Indicator Reports, for the period 2005 to 2016, show that on average there are significant program delays in 43% of all construction projects.[8] While delays to CLT buildings will occur, only 7 of the case study projects reported a delay directly resulting from the CLT.

DELIVERIES

The just-in-time delivery process avoids unnecessary storage on site and double handling of the panels. The CLT provider, with a good understanding of the assembly rate and delivery issues, should schedule this in conjunction with the main contractor. However, with no buffer of stored panels, in the event that a delivery is delayed the full assembly has to stop. In the 100 buildings two responses mentioned a direct delay from the panel deliveries and site access, indicating that the time savings achieved through avoiding double handling appear to outweigh any risk.

WEATHER

While it is preferable to build during the dryer months of the year, CLT structures can be erected in any season and are less vulnerable to wet weather than in-situ concrete. Unpredictable weather can, however, cause delays on site, particularly on exposed sites.

The safety of assembling large format panels during high winds needs to be considered. Two of the case studies reported delays due to high winds that halted the panel assembly.

CLT frames require protection from prolonged exposure to standing water following rain. Failure to provide this can lead to the issues discussed on page 54.

Where the CLT is to be exposed, a lack of sufficient protection can lead to staining. In most cases water mark stains can be removed by sanding down the surface of the panels. However, in the worst case, panels would have to be replaced or the design changed to include linings.

Careful programming and procurement is required to ensure that covering-up trades directly follow on after the installation. It is also essential to clearly delineate whether the subcontractor or main contractor are responsible for brushing off standing water.

WATER

Consideration of the sequencing should be given at the early stages to minimize the time between delivery and installation of the panels. The CLT should be protected during storage and, once installed, particular attention given to sealing the end grain to the edges of the panels, which is the principal vulnerability.

Where CLT is allowed to get wet, it can swell leading to thickening of the panels. If the source of moisture is removed quickly and adequate airflow is maintained, the CLT will revert to its manufactured moisture content and original dimensions.

Minor exposure is not usually an issue, however where parts of the structure have been subject to significant prolonged water exposure, they should be allowed to dry before further CLT is added to avoid any dimensional issues.

Most importantly, the CLT must be dry in any situation where waterproof membranes are applied. Where this is not ensured, the moisture can be trapped and this could cause long term deterioration of the timber.

As in all construction, workmanship is a key consideration to ensure the building performs as designed. For example, gaps in insulation layers can cause a condensation risk.

SUNLIGHT

Where CLT is designed to be exposed, consideration should be given to the effect of UV light as certain woods can darken fairly rapidly when exposed to the sun. In particular, spruce can tend to redden which can have an impact on the desired tones or cause marks where some parts of the board have been exposed more than others.

FIRE

ON SITE

The risk of fire during construction is a key factor for consideration. As previously explained, CLT panels themselves will not easily catch alight and start a fire. However on construction sites there are many other sources for the potential initiation of a fire, from stored and waste materials to construction equipment.

Keeping the site clean and clear of rubbish is essential, as is ensuring all protocols are followed. A fire strategy should be produced during construction on all building sites, not just those for CLT, as the storage of materials and use of many different forms of equipment make construction a high-risk period. In our 100 schemes 40 had a specific fire strategy produced for the construction period. This was more common for large-scale buildings where the risks, complexity and time on site make this more involved.

An example of a fire strategy on a tight urban CLT site is at Pitfield Street in Hackney (pg.232-233). This is bounded on three sides by residential and commercial buildings, and a detailed strategy is in place to protect staff, visitors and neighbors as well as the timber structure and adjacent premises.

Fire safety coordinators were appointed to be responsible for this, and for reassessing the changing escape routes and risks with every floor of the timber structure as it was erected. This includes a radiant heat timber risk analysis and consultation with external fire consultants and local fire station staff.

A secure and tidy site, with adequate escape routes, firefighting points, detection and emergency lighting are essential. A system with call points, sirens and heat detection as well as smoke detection was used in this case, with a maximum 80ft (24m) escape distance from any one point, and careful management of any flammable liquids or combustible materials kept on site.

The UK's Structural Timber Association first published "16 Steps to Fire Safety' in 2008.[9] This guidance note specifically addresses the prevention and suppression of fire on timber frame construction sites. The note was updated in 2014 to include all structural timber construction.[10]

The 16 steps were followed in 28 of the projects, of which 18 were undertaken since the publication of the more comprehensive guidance in 2014, demonstrating an increasing number following these essential guidelines each year.

Only one of the projects reported an on-site fire, the GSK Centre for Sustainable Chemistry (pg.158-159). In 2013, when the building was approximately two-thirds complete, a fire started with a faulty generator and caused substantial damage. There was no loss of life and the building was reconstructed almost exactly as per the previous design. The review that followed the event found no fault with the design team, the design or the mitigation measures installed.[11]

OFF-SITE

In any urban site, consideration should be made to mitigate the risk of fire spread should it occur – the 'off-site' fire risk. The 2014 STA publication, 'Design guide to separating distances during construction' deals with this issue by providing minimum safe distances between exposed CLT surfaces on a construction site and adjacent buildings.[12] Where it is not possible to achieve these minimum distances, the guidance advises that fire protection to the external surfaces be included to reduce the potential for heat transfer.

In most cases where the site is in close proximity to other buildings a specialist consultant will be required to advise on necessary measures. Such measures might include temporary infilling of services penetrations, windows and door openings in party walls.

INSURANCE

Insurance companies assess necessary risks and codify them . Key issues in using CLT center around fire safety and durability, particularly in regard to moisture.

CLT is a softwood product and is not intended to be permanently exposed to the elements. If sufficiently protected and well detailed there is no reason the material should deteriorate over time. The manufacturer KLH has obtained a Durability Report from the BRE (Building Research Establishment) for a 60-year lifespan,[13] but there is no reason CLT should not exceed this. In some countries durability concerns are addressed with chemical treatments; in Australia to address termite damage risk, and in France where Boron is used to mitigate against risk of rot resulting from long term leaks in bathrooms.

Treatment with chemicals can reduce the opportunity to reuse or recycle the timber at the end of life so it is generally considered preferable to address the cause through good detailing and correct installation as opposed to mitigating the result.

Insurance policies taken out by contractors and/or clients which cover risk of damage to the building during construction covers any number of risks and factors, however the most common query raised in relation to CLT structures relates to fire risk.

Periodic devastating conflagrations on timber frame construction sites lead to a predictable concern, however the risks on CLT sites are not the same as for timber frame. As more CLT buildings are completed, the knowledge and experience of how to mitigate fire in CLT construction has grown. Over recent years the UK guidance on fire risk during construction for timber framed structures has been extended and adapted to cover CLT. The UK Timber Frame Association and subsequently the STA have worked with fire engineers to produce guidance that covers all aspects of fire safety during construction. These are covered in more depth in the chapter on fire.

The majority of CLT building projects reported no issues with obtaining insurance during construction if the guidance was followed. Where space restrictions or other considerations prevented meeting the guidance, a specialist fire engineer would be commissioned to devise specific strategies.

A principal contractor, Jerram Falkus, (pg.192-193) reported both lengthy discussions with their insurers and a small premium for their first CLT project but indicated that for subsequent projects these dropped away once their insurers had greater knowledge of the product and had witnessed it under construction. The key being to work through the issues to address any concerns, with backup evidence provided by engineers and manufacturers.[14]

Another large contractor, Mace, (pgs.246-247, 250-251 & 278-279) reported a small insurance premium of £6,000 (equivalent to $8,000) on the CLT element of their Highpoint scheme, plus some additional costs in instigating fire safety measures on site, such as addressing fire spread risk to neighboring buildings with fire rated scaffold sheeting. However, they chose CLT over concrete for this building due to it's overall cost and time benefits.[15]

Lendlease, an international contractor and developer, reported no increase in insurance premiums for CLT projects, however additional fire safety measures were required during construction, for instance metal scaffold boards rather than timber were required to reduce fire load.[16]

Endnotes

1 Ian Brooks, Kier Eastern, interview by R.Sawcer, 12 September 2017, Telephone.

2 The Concrete Centre, Cost and Program, 2017 <http://www.concretecentre.com/Performance-Sustainability-(1)/Cost-Program.aspx> [accessed: 20 August 2017].

3 Questionnaire from Liam Dewar, Eurban, 15 September 2017.

4 Questionnaire from Kay Hartmann, KLH UK, 11 September 2017. Questionnaire from Gareth Mason, Stora Enso, 8 September 2017. Questionnaire from Liam Dewar, Eurban, 15 September 2017.

5 Questionnaire from Gareth Mason, Stora Enso, 8 September 2017.

6 Gavin White, Ramboll, interview by A.Thistleton & R.Sawcer, London, 8 September 2017, Waugh Thistleton Offices.

7 Questionnaire from Gareth Mason, Stora Enso, 8 September 2017.

8 Glenigan, Constructing Excellence, CITB and Department for Business, Energy & Industrial Strategy, UK Industry Performance Report, Based on the UK Construction Industry Key Performance Indicators, 2016 <https://www.glenigan.com/sites/default/files/UK_Industry_Performance_Report_2016_LR.pdf> [accessed 12 September 2017].

9 Structural Timber Association, *Fire during construction,* presentation, 2015 <http://www.firefighterscompany.org/news/STA-2015.pdf> [accessed 20 September 2017].

10 Structural Timber Association, *Detailed explanation of the '16 Steps to Fire Safety' strategy*, 2017 <http://www.structuraltimber.co.uk/wms/do.php?module=core&action=user-login&target=L2dldC1kb3dubG9hZC81MTMx> [accessed 20 September 2017].

11 Ike Ijeh, Carbon Neutral Laboratory: Out of the ashes, Building, 16 November 2016. <https://www.building.co.uk/carbon-neutral-laboratory-out-of-the-ashes/5084942.article?adredir=1> [accessed 27 July 2017].

12 Structural Timber Association, *Design guide to seperating distances during construction,* 2015 <http://www.structuraltimber.co.uk/wms/do.php?module=core&action=user-login&register=1&target=L2dldC1kb3dubG9hZC81MDYy> [accessed 10 December 2017].

13 KLH UK, Frequently Asked Questions, 2017 <http://www.klhuk.com/media/11553/frequently%20asked%20questions_05042011_1.pdf> [accessed 10 July 2017].

14 Simon Birnie, Jerram Falkus, interview by T.Westwood & R.Sawcer, London, 22 September 2017, Waugh Thistleton Offices.

15 Guy Hunt et al., Mace, interview by T.Westwood, 26 September 2017, Telephone.

16 Richard Cook, Lendlease, interview by A.Waugh, T.Westwood & R.Sawcer, 29 September 2017, Telephone.

POST COMPLETION

There is a perceived resistance from lenders and insurers to back CLT which can result in clients' reluctance to adopt the material. From the case studies in this book this perception is shown to be false.

The overwhelming feedback from visitors and users of completed CLT structures is highly positive in terms of aesthetic and comfort but also how warm and quiet people find the spaces.

At Woodberry Down, Berkeley Homes have reported fewer overheating events in the common parts, due to the lower thermal mass of the structure, and substantially less movement resulting in reduced cracking to the internal finishes.

A number of formal post-occupancy evaluation studies are now under way which should provide more empirical data to add to the anecdotal evidence.

Image: Barretts Grove, Groupwork + Amin Taha © Tim Soar

MORTGAGES & SALEABILITY

In the UK, there have been no reported issues in obtaining mortgages for homes constructed from CLT. This includes single family dwellings and mid-rise multi-home schemes.

Lenders will generally rely on the approval of the Council for Mortgage Lenders (CML) in order to provide mortgages for any particular construction type. The CML in turn wants to see that warranty providers are willing to provide warranties. Lendlease reported that this was their route to satisfying mortgage lenders on behalf of their purchasers; by obtaining approval from the NHBC.

At Murray Grove (pg.178-179), the developer was keen not to overstate the timber structure however the agents reported no reduction in value or desirability in the flats. Indeed, the flats retained their value through the housing downturn of 2009-2012. With more CLT structures being completed and more public knowledge of the material, the quality benefits are more widely appreciated, especially where some CLT is exposed. For many buyers the carbon credentials of the material are also seen as a positive.

INSURANCE

As well as there being no reported issues with obtaining insurance cover during construction, there have been no problems with buildings insurance, which is taken out by the building owner and covers the completed property against damage or loss. Lendlease have reported no issues in insuring CLT buildings post completion, and there was no additional premium for insuring a CLT building over other construction types.

BUILDING WARRANTIES

There is often a benefit to developers obtaining a third party, insurance-backed warranty for the completed building from a specialist insurer. These sit above specific product or installation warranties provided by manufacturers or subcontractors and any contractual warranty from consultants. Warranty providers' standards are extensive and rigorous with reviews of construction details and strategies through the design stages and regular inspections through construction. These largely follow building control guidance, but individual insurers can have specific areas of interest where their requirements exceed the Building Regulations.

Sectors tend to operate differently. New build housing is often sold with a 10 year warranty. The National House Building Council (NHBC) were the first to offer this, and there are now other providers in the UK market. These warranty providers have technical teams with construction industry experience who can engage with the consultants at design stages and help agree solutions that meet their criteria. In this sense CLT is treated no differently to any other 'non-standard' construction technology.

NHBC provided a warranty for Murray Grove in 2008; (pg.178-179), their first pilot residential scheme constructed entirely from CLT panels above first floor slab. Whilst they advised that subsequent schemes would still be assessed by them on a case-by-case basis, the details developed and the knowledge obtained has informed their response in subsequent CLT residential projects.

MAINTENANCE AND REPAIRS

Where CLT has been damaged, for example by fire or water penetration, repair is possible, either by replacement of the damaged timber or reinforcement of the affected area.

In the first instance, where any damage is encountered, a structural appraisal should be carried out to establish whether urgent action is required to restore stability. Repairs to damaged elements can often be performed by cutting out the effected area and scarfing or splicing in new material. Where the damage is close to a junction, it may be necessary to reinforce the area with steel brackets to ensure robustness.

In cases of severe damage, whole panels may need replacing. In these cases, the surrounding structure should be propped, the panel cut out and a new panel or panels fixed in place.

FIRE

In many CLT structures, the timber provides part of the fire resistance so there is a degree of structural redundancy. In the case of a minor fire, where charring has occurred, it is therefore likely that the load-bearing section of the element is still intact.

In this case it would usually not be necessary to reinforce the structure, however, the fire protection should be restored, either by replacement of the effected timber or by addition of a fire resistant lining. Where larger fires have occurred and one or more structural elements have been severely damaged, it may be possible to remove and replace the entire element.

WATER

Long term exposure to high levels of moisture can lead to decay of the timber. Even small amounts of moisture, if allowed to penetrate the timber, can cause detrioration if not allowed to evaporate away, which is why it is essential to ensure the timber is dry before roof membranes are laid.

Where water damage is discovered, it is essential to ensure that all effected areas are identified as water can traverse CLT structures and build up in areas some distance from the original source.

Where long term damage has occured, testing core samples to ensure structural integrity may be a less expensive solution than replacing entire panels.

Once structural integrity has been ensured, all areas should be allowed to dry out before the damage is cut away and replaced through gluing, screwing or nailing additional timber. An engineer will be required to ensure structural integrity.

If the water penetration is a result of an inherent vulnerability, such as in a roof gulley, chemically protecting the repaired timber should be considered.

MONITORING AND EVALUATION

Incorporating monitors within the fabric of a CLT building can be useful to measure movement of the structure or moisture levels which can give early warnings of any failures and mitigate issues such as leaks. Moreover, data collected from monitoring devices can help improve our ability to accurately design for key factors such as thermal and acoustic performance, through expanding our as-built database for CLT. Relying on monitors, which tend to be buried behind finishes and therefore not easily maintained, can be a risk if this is the only measure to ensure performance.

Several of the case studies reported a desire to incorporate some form of monitoring however few were implemented.

Data from the select studies currently under way will help us to understand and assess the longer term behavior of CLT in a range of situations.

The Architecture Archive (pg.244-245) is currently undergoing environmental monitoring and, particularly as a pure/solid CLT build up should produce easily extrapolated data on this materials true dynamic performance.

Similarly, at Woodberry Down (pg.218-219), a monitoring program is currently being established for both the CLT case study scheme and an adjacent traditional new-build block, which will aim to generate useful comparative data for designers, covering a number of areas:

Energy Use - comparing the energy used per apartment between the two schemes.

Humidity - testing to what extent the natural hygroscopic performance of CLT regulates the internal humidity, especially in bathrooms. Also to measure whether moisture builds up in the structure or is able to migrate to outside air.

Vibration - measuring the building's deflection at roof level to compare with the design assumptions. Also monitoring vibration at slab level from live loads.

Thermal Performance - taking measurements to monitor the comfort levels within different units and through comparison with the adjacent concrete building, to determine to what extent the timber affects these comfort indicators.

Resident Satisfaction - while there are number of reports of high levels of resident satisfaction in CLT buildings, a formal feedback process will be helpful to benchmarks these..

CASE STUDIES

The following section contains the 100 case study projects, categorized into four broad sectors: Residential, Education, Commercial and Public & Civic.

The 100 case studies comprise:

- 32 Education buildings
- 32 Residential buildings (13 of which are Private)
- 15 Commercial buildings
- 21 Public & Civic buildings

The uneven spread across the sectors is indicative of the tendency to use CLT for certain applications with the vast majority built to date being residential and education buildings.

The embodied carbon figures listed for each project indicate the net carbon saved within the timber superstructure only. This considers both the carbon sequestered in the timber (expressed as negative emissions) and the carbon produced in the manufacture and delivery of the panels. It is important to note that in a full embodied carbon calculation this aspect of the building would only form part of the overall carbon cost of the construction, evaluated alongside the foundations, other structural materials within hybrid schemes, finishes and cladding, however to indicate the significance of the timber itself we have focused on this aspect alone.

The above ground structures have been categorized as 'Pure CLT' (CLT alone), 'Pure Timber' (CLT combined with other timber elements such as glulam), or 'Hybrid' (CLT combined with other structural materials such as steel or concrete). These categories give an indication of the significance of the timber's carbon savings as in 'Hybrid' schemes the emissions from steel/ concrete will also have an impact.

Some carbon savings quoted for engineered timber structures include the mitigated carbon that would have been emitted were the same scheme to have been built traditionally. Whilst this saving is very real and does affect overall carbon emissions from the industry it was not possible to confidently quote this for all schemes without complex structural analysis.

Image: Curtain Place, Waugh Thistleton Architects © Ben Clarkson

CONTENTS

RESIDENTIAL

CLT as a product was initially developed to be aimed at the residential sector. Since then it has been consistently popular in these projects. The maximum span that can be achieved with CLT panels of average thickness is similar to the proportions of typical residential spaces. Due to this relationship, pure CLT structures, using little or no glulam/steel, are usually possible.

Residential projects constructed in CLT largely fall within one of two main categories. The first being individual one-off dwellings, typically where the client is building their own house. The use of CLT here is often driven by aesthetics, desire for exposed timber finishes and building sustainability. Time saving is usually less significant to clients of this type of scheme, whose primary focus tends to be on the creation of a high quality and beautiful home. For small low rise projects, where structural demands are less, CLT can provide a great deal of freedom in design which can lead to some interesting and impressive volumes. The natural robust walls are tactile, with an inherent ease of fixing to the structure. The lower requirements for fire and acoustics within individual dwellings mean exposing the timber is usually an easier process.

The second category is high-density, mid-to-high rise housing blocks. Here the key drivers for using CLT tend to be the ease and speed of construction. In such schemes the CLT is rarely exposed. This is primarily due to the fact that for these schemes the CLT itself is typically not capable of meeting the stringent requirements for fire and acoustics unless lined to at least one face. In addition to this, particularly for earlier schemes, issues with obtaining insurance and fears over the saleability of flats led to a client desire to conceal the structure's nature.

The potential to use CLT to create vast honeycomb structures delivering the many cellular volumes of a high-density housing scheme means that the program benefits offered by CLT can be truly optimized.

Image: Woodblock House, dRMM © Alex de Rijke

© Edmund Sumner

2005

Residential

CARLISLE LANE

Pringle & Richards LLP

LOCATION
London Borough of Lambeth

HEIGHT / STOREYS
20 ft (6 m) / 2 storeys

CONSTRUCTION COST
£350,000

ARCHITECT
Pringle Richards Sharratt

STRUCTURAL ENGINEER
Alan Baxter Ltd.

TIMBER ENGINEER
Eurban

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Züblin Timber (formerly Finnforest Merk)

MAIN CONTRACTOR
DF Keane / Züblin Timber

TIMBER VOLUME
1,700 ft^3 (74 m^3)

TIMBER ASSEMBLY
2 weeks

OVERALL CONSTRUCTION
36 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-28 tons (-26 tonnes) CO_2e

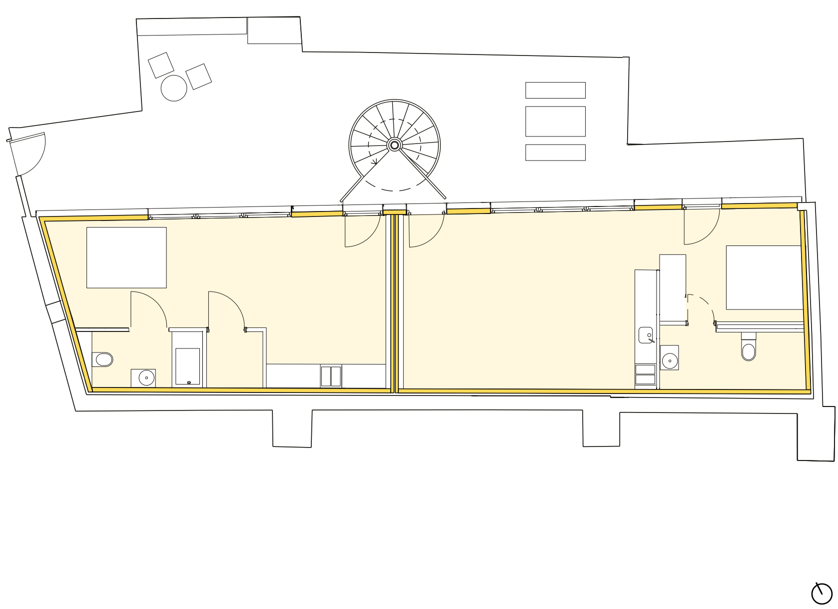
CLT FACT
Lightweight CLT facilitated building on poor ground conditions

3 Carlisle Lane is a two-storey new-build residential scheme comprising four one-bedroom apartments on a tight urban site. Poor ground conditions combined with the site's close proximity to a railway viaduct necessitated a lightweight structure with good acoustic properties. The solution was to construct the entire building envelope from prefabricated lightweight solid timber panels.

The site extends 65 foot back from Carlisle Lane but has a street frontage of just 23 foot. The concept was to split the site in two, with a long thin strip of built accommodation occupying the southern side and a private courtyard occupying the northern side. This approach was partly driven by the fact that three of the site boundaries are party walls and new window frontage could be created only within the site itself.

The new timber structure was built within the existing masonry perimeter walls which provide additional fire resistance, thermal mass and acoustic protection from the adjacent railway viaduct.

The lightweight nature of the CLT structure meant that the slab to the warehouse could also be retained with a new concrete raft cast over the top to spread the load. This obviated the need for more substantial foundations and piling on the poor quality ground, reducing costs.



First Floor Plan

© Anthony Coleman

2006

Residential

FAIRMULE HOUSE

LINT Group

LOCATION
London Borough of Hackney

HEIGHT / STOREYS
45 ft (13.8 m) / 5 storeys

CONSTRUCTION COST
£1.6 million

ARCHITECT
Quay2c Architects

STRUCTURAL ENGINEER
Anders Associates

TIMBER ENGINEER
Eurban

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Züblin Timber (formerly Finnforest Merk)

MAIN CONTRACTOR
L I Construction

TIMBER VOLUME
15,000 ft³ (425 m³)

TIMBER ASSEMBLY
5 weeks

OVERALL CONSTRUCTION
65 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-267 tons (-242 tonnes) CO_2e

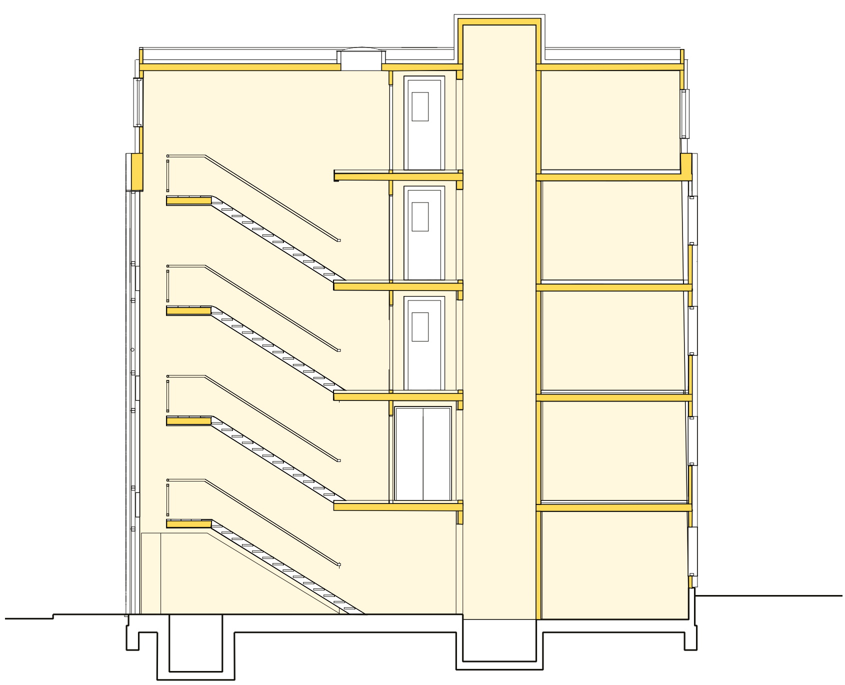
CLT FACT
Largest early mixed use building in the UK using CLT, including lift shaft

Thomas Fairchild, the first man to genetically modify plants to manufacture his famous "Fairchild Mule" hybrid, is buried in the pocket park to the rear of the site. The scheme was conceived with this in mind, and the desire to create a hybrid building 'made from nature' drove the concept.

Originally designed for concrete and steel, a review of the scheme resulted in 11 dual aspect, cross-ventilated apartments, all but one of which have a private balcony or terrace. Apartments are accessed from two naturally lit common staircases which encourage horizontal circulation to take place in the street rather than the dark corridors of the original design. The ground and first floor provide seven commercial units of varying sizes to encourage a greater diversity of uses to compliment the flats above.

One of the first CLT buildings within the UK the timber sits on a concrete slab with a small steel portal to the ground floor of the 5 storey part of the building. Timber soffits are exposed throughout the apartments, a key requirement of the design.

The façades of the building are inspired by the Fairchild Mule including bespoke public art by Quay 2c's Julia Manheim. The galvanized steel panels used on the elevation recall watering cans, while the garden elevation is covered with timber shingles.



Section

© Ed Reeve

2007

Residential (Private)

SUNKEN HOUSE/ED'S SHED

Ed Reeve

LOCATION
London Borough of Hackney

HEIGHT / STOREYS
23 ft (6.9 m) / 3 storeys

CONSTRUCTION COST
Undisclosed

ARCHITECT
Adjaye Associates

STRUCTURAL ENGINEER
Techniker

TIMBER ENGINEER
Eurban

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Züblin Timber (formerly Finnforest Merk)

MAIN CONTRACTOR
Ed Reeve

TIMBER VOLUME
2,600 ft^3 (74 m^3)

TIMBER ASSEMBLY
1 week

OVERALL CONSTRUCTION
52 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-46 tons (-42 tonnes) CO_2e

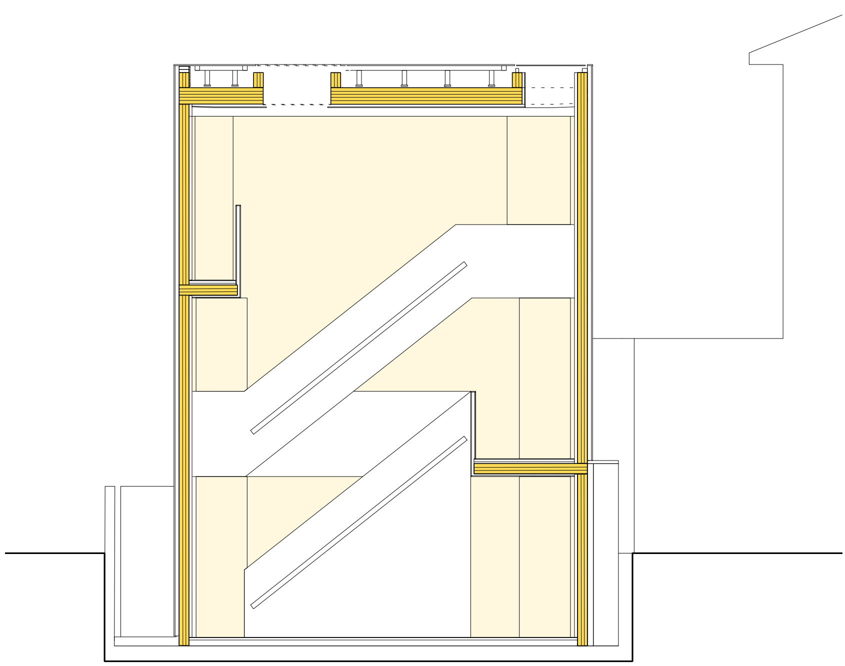
CLT FACT
CLT assembly in one week

Sunken House, known affectionately as 'Ed's shed', is a three-storey family home in North Hackney designed for photographer Ed Reeves. The design of the home responds to its immediate context, drawing from the local architecture of Victorian terraced houses and warehouse workshops.

Viewed from the street, the house appears to have the same habitable volume as the adjacent semi-detached villa, and the flat roof of the cuboid structure aligns with the warehouse opposite. However Ed's shed has been sunk an entire storey to maximize the interior space. Standing in an excavated courtyard, which is not overlooked by the adjacent buildings, the main living space is located at basement level. The bedrooms are on the first floor, and there is a large studio on the second floor which benefits from a view of other people's gardens without intruding on their privacy.

All façades of the house and the horizontal surface of the concrete patio are clad in a timber rainscreen of dark stained cedar.

The CLT upper levels, which sit on the excavated concrete lower floor were erected in a single week, substantially reducing the overall construction program.



Section

© David Butler

2008

Residential (Private)

CAVENDISH AVENUE

Hugo Macey & Hajni Elias

LOCATION
Cambridge

HEIGHT / STOREYS
28 ft (8.4 m) / 3 storeys

CONSTRUCTION COST
Undisclosed

ARCHITECT
Mole Architects

STRUCTURAL ENGINEER
Ramboll / Whitbybird

TIMBER ENGINEER
Ramboll

TIMBER CONTRACTOR
KLH UK

TIMBER MANUFACTURER
KLH Massivholz

MAIN CONTRACTOR
Cambridge Building Company

TIMBER VOLUME
2,600 ft^3 (74 m^3)

TIMBER ASSEMBLY
1 week

OVERALL CONSTRUCTION
43 weeks

STRUCTURE TYPE
Pure Timber

EMBODIED CARBON WITHIN TIMBER*
-45 tons (-41 tonnes) CO_2e

CLT FACT
Measured in-use energy efficiency meets Passivhaus standards

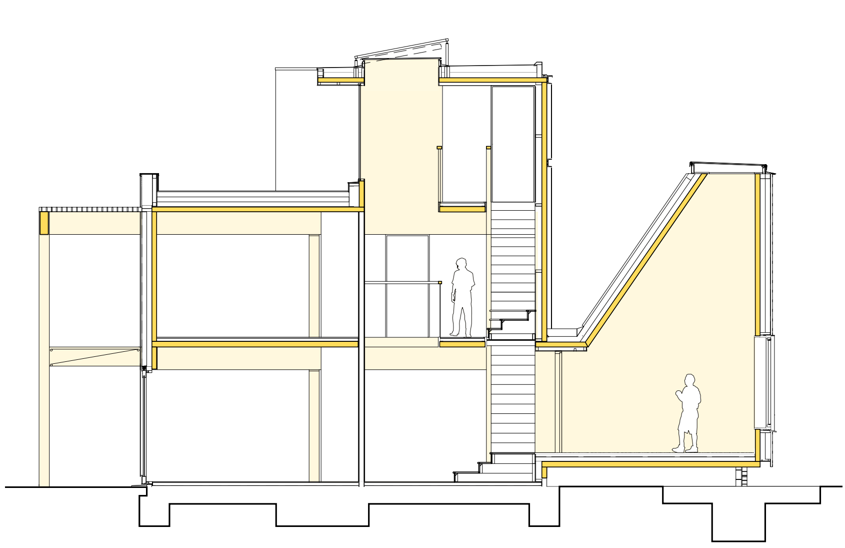
Cavendish Avenue house re-interprets the suburban villa, replacing a 1930s detached home in a tree-lined suburban enclave of Victorian and Edwardian detached houses close to the centre of Cambridge.

The building is constructed of CLT panels, supported by glulam beams and columns. The north-facing front elevation is clad in a semi-reflective patterned glass rain-screen, with a pitch-roofed shingled structure extending into the front lawn from the first storey. Enclosed separately from the main house, this intimate, timber-lined music room references the surrounding architecture.

A skeleton of the glulam beam structure extends to the rear to form a solar shading portico in the garden. Roof-lights can be opened for ventilation, whilst large sail rigs hung across the portico beams on the rear façade provide shade and prevent the house from over-heating.

The solid floors act as a thermal heatsink, minimizing the need for additional heating. The dark basalt tiles on the internal ground floor absorb heat during the day, which is slowly released overnight. A ground-source heat pump provides hot water and the minimal heating required.

The building uses less than the target of 4,750 Btu/ft^2 (15 kWh/m^2) for space heating – equivalent to German Passivhaus standards.



Section

© Will Pryce

2009

Residential

STADTHAUS/MURRAY GROVE

Metropolitan Housing Trust / Telford Homes PLC

LOCATION
London Borough of Hackney

HEIGHT / STOREYS
95 ft (29 m) / 9 storeys

CONSTRUCTION COST
£3.86 million

ARCHITECT
Waugh Thistleton Architects

STRUCTURAL ENGINEER
Techniker / Jenkins & Potter

TIMBER ENGINEER
Techniker / KLH UK

TIMBER CONTRACTOR
KLH UK

TIMBER MANUFACTURER
KLH Massivholz

MAIN CONTRACTOR
Telford Homes

TIMBER VOLUME
31,800 ft^3 (901 m^3)

TIMBER ASSEMBLY
9 weeks

OVERALL CONSTRUCTION
49 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-557 tons (-505 tonnes) CO_2e

CLT FACT
If built today it could use 30% less timber due to modern analytical tools

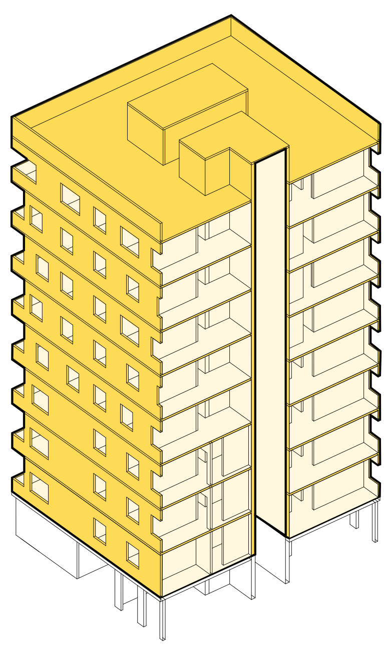
This was first tall building using engineered timber, and was the tallest timber residential structure in the world at the time of completion. The entire structure above first floor slab is comprised of CLT panels, with all walls, floor slabs and lift cores formed in solid timber which act together, like a honeycomb, providing a very stable and efficient building.

The building form is an extrusion of the site footprint to 9 storeys, which was largely predetermined by planning constraints. The client required separate entrances for affordable and private apartments which resulted in a mirrored ground floor plan from east to west. Different layouts are used throughout the building to accommodate a mix of family units and smaller apartments. These are facilitated through the use of load-bearing CLT panels, which form party walls and some internal partitions.

The distinctive pixelated façade is made up of 2,500 individual panels in three hues, which are arranged to capture how shadows fall across the building. The lightweight wood-pulp cladding avoids adding unnecessary bulk to the tower.

In creating a world first, the design team, contractor and timber supplier had to collaborate closely and work together with the client to overcome regulatory hurdles and demonstrate the resilience and safety of the building.

This exemplar project has spearheaded the introduction of CLT in the UK, and pioneered an international movement in tall timber construction.



Axonometric of CLT

© ACME

© ACME

2009

Residential (Private)

HUNSETT MILL

Private Client

LOCATION
Stalham,Norfolk

HEIGHT / STOREYS
21 ft (6.5 m) / 2 storeys

CONSTRUCTION COST
Undisclosed

ARCHITECT
ACME

STRUCTURAL ENGINEER
AKT II

TIMBER ENGINEER
Eurban / AKT II

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Züblin Timber (formerly Finnforest Merk)

MAIN CONTRACTOR
Willow Builders / Eurban / Nuttall

TIMBER VOLUME
2,900 ft^3 (82 m^3)

TIMBER ASSEMBLY
2 weeks

OVERALL CONSTRUCTION
43 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-51 tons (-46 tonnes) CO_2e

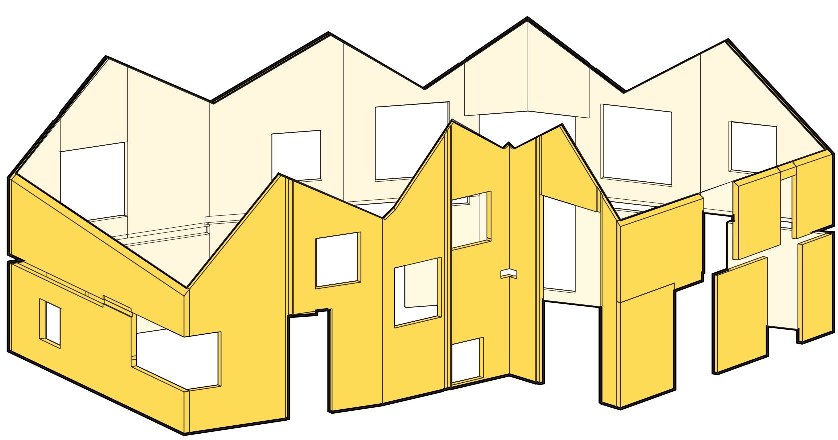
CLT FACT
Open ground floor space created by hanging first floor plate

The extension to this 19th century mill keeper's cottage sits adjacent to the Grade II listed mill. Since the end of its working life in 1900, the house has been a private residence, extended with a series of ill-conceived add-ons which had caused subsidence and repeated flooding. When further space was required it was decided to re-instate the house to its original proportions with only a single extension to one side.

The extension is designed as a shadow of the existing house which retreats behind the listed mill. Clad in dark charred cedar boards the geometry of the extension appears ambiguous from afar. A series of undulating pitched roofs mimic the local vernacular.

The extension is made entirely from CLT which is exposed as interior finish. The unique geometry of the roof forms a stiff plane from which the first floor is hung, allowing for a large, open-plan ground floor.

The design considered its embodied energy and method of construction alongside the efficiency during occupation. In addition to the timber structure, ground source heat pumps, passive solar heating and an independent water-well make the house almost completely self-sufficient, creating a home that is aesthetically innovative, responsive to contemporary needs and sensitive to its surroundings.



Isonometric CLT Panel Diagram

© Tim Soar

2009

Residential (Education)

RUSSELL STREET

St Catherines College Development Ltd

LOCATION
Cambridge, Cambridgeshire

HEIGHT / STOREYS
39 ft (12 m) / 1.5 - 4 storeys

CONSTRUCTION COST
£2.6 million

ARCHITECT
5th Studio

STRUCTURAL ENGINEER
Michael Hadi Associates

TIMBER ENGINEER
Michael Hadi Associates / Eurban

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Schilliger Holz

MAIN CONTRACTOR
SDC

TIMBER VOLUME
8,800 ft^3 (250 m^3)

TIMBER ASSEMBLY
4 weeks

OVERALL CONSTRUCTION
50 weeks

STRUCTURE TYPE
Pure CLT

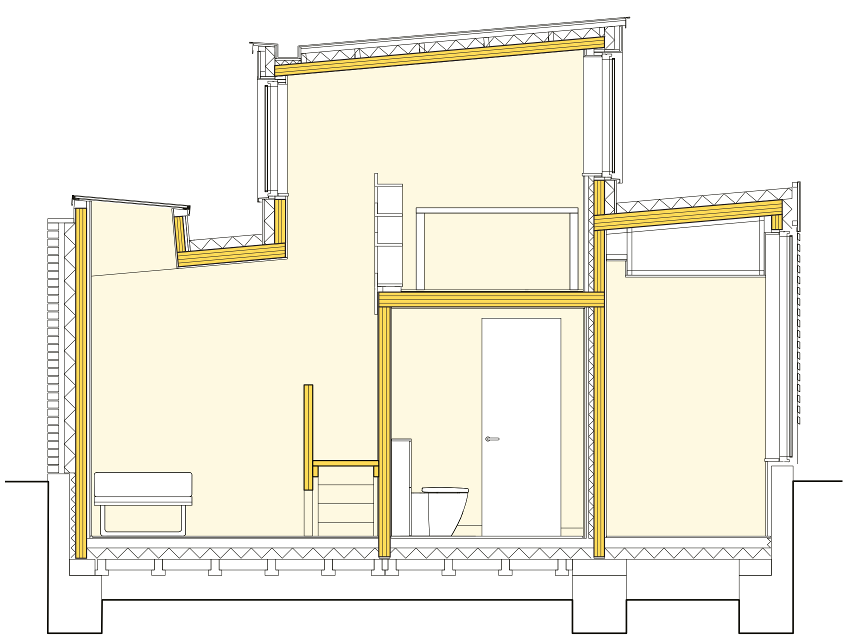
EMBODIED CARBON WITHIN TIMBER*
-161 tons (-146 tonnes) CO_2e

CLT FACT
Speed of construction enabled tight program to be met

While the city fringe college site offers a generous garden space, the poor positioning of the original building and overlooking caused by adjacent plots had created awkward relationships between buildings. This project adds twenty-two rooms and capsule apartments, re-focusing the existing buildings around a green garden court to create an intimate college setting that politely screens adjacent sites.

Site constraints dictated it was necessary to build up to an irregular boundary on three sides. The choice of CLT for the structure meant that through the precision manufacturing process every dimension could be exactly specified. The relatively slender structural profiles of the floor, roof and wall panels (with no downstand beams or ribbed structures) maximized the useable volume of the new building.

Newly built rooms face the courtyard and are brought together by generous corridors, echoing the traditional architecture of Cambridge colleges. The ground floor duplex rooms that define the courtyard edges are ingeniously planned in cross section, allowing double height space, natural light sources and cross ventilation to each room. Selectively exposed CLT offers a warm and aesthetically pleasing finish; suitably robust and requiring minimal maintenance or decoration. The exposed timber buffers moisture and VOC's, contributing to high air quality and comfort conditions throughout the building.



Section

© David Grandorge

2010

Residential (Private)

STRANGE HOUSE

Hugh Strange / Adriana Ferlauta

LOCATION
London Borough of Lewisham

HEIGHT / STOREYS
12 ft (3.7 m) / 1 storey

CONSTRUCTION COST
£170,000

ARCHITECT
Hugh Strange Architects

STRUCTURAL ENGINEER
Price & Myers

TIMBER ENGINEER
Eurban

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Schilliger Holz

MAIN CONTRACTOR
Solmaz

TIMBER VOLUME
800 ft^3 (22 m^3)

TIMBER ASSEMBLY
1 week

OVERALL CONSTRUCTION
30 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-13 tons (-12 tonnes) CO_2e

CLT FACT
CLT could be craned in over the existing walls

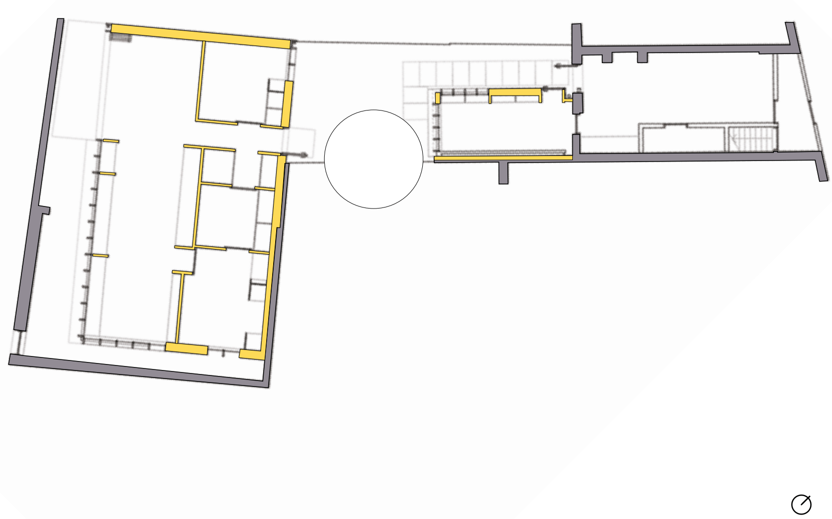
Situated within the brick walls of an old pub yard the two bedroom house and adjacent studio occupy the site extensively.

While only 830ft², the house feels deceptively large with spaces stretching 10ft high and, 36ft long, enfilade rooms, and framed views. A narrow space between the house and perimeter wall links the inside and outside spaces.

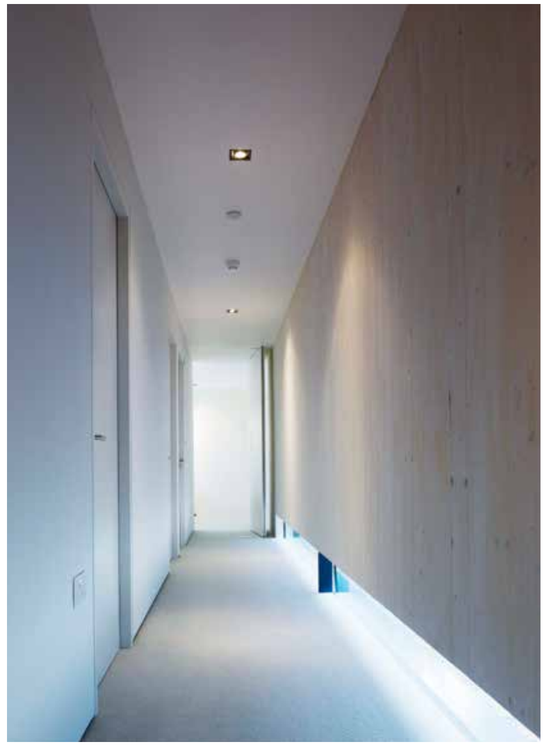
The structure is formed of CLT panels that were craned over the existing wall and fixed into place over the period of just one week. White-washed and left exposed internally, the primary structure has a strong relationship with the secondary timber fit-out. Glass is sandwiched between exposed structural timber and hardwood frames to form windows. Internal doors are face-fixed to structural openings, and the kitchen, cupboards, seating and shelving units sit within recesses formed in the structural frame.

Every space has the same palette of simple materials: concrete floors, white-washed CLT walls and ceilings; dark hardwood windows, doors and furniture.

Fibre-cement panels envelope the building's exterior; their lightness and verticality relating to and contrasting with the weight and horizontality of the rough in-situ concrete base situated on top of the existing slab.



Ground Floor Plan


© James Morris

2010

Residential (Private)

WATSON HOUSE

Private Client

LOCATION
Boldre, Hampshire

HEIGHT / STOREYS
13 - 17 ft (3.9 - 5.3 m) / 2 storeys

CONSTRUCTION COST
£640,000

ARCHITECT
John Pardey Architects

STRUCTURAL ENGINEER
Ramboll

TIMBER ENGINEER
KLH UK

TIMBER CONTRACTOR
KLH UK

TIMBER MANUFACTURER
KLH Massivholz

MAIN CONTRACTOR
NFTS

TIMBER VOLUME
3,500 ft^3 (99 m^3)

TIMBER ASSEMBLY
1 week

OVERALL CONSTRUCTION
43 weeks

STRUCTURE TYPE
Hybrid

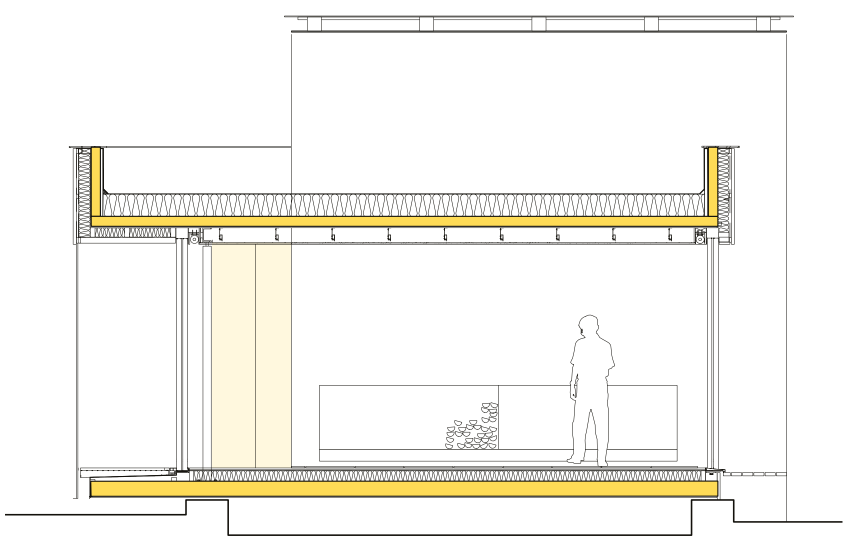
EMBODIED CARBON WITHIN TIMBER*
-63 tons (-58 tonnes) CO_2e

CLT FACT
CLT used for continuation of low-impact design

The house replaces a large suburban style two-storey house in a rural site within the New Forest. The design responds to both the client's desire to live in close contact with nature and the idea of making the house invisible from the public realm to deal with restrictive local planning policy.

This has resulted in a long, low pavilion that 'touches the earth lightly'. Orientated north-south the rectangular form provides three bedrooms that open up to the east and morning light. A large open-plan living-dining-kitchen area, and a master bedroom suite and study, open to the west with views into a pine copse. A brick chimney and hearth, built in Danish brick, anchors this delicate pavilion to the site.

The low-impact design is extended to the materials and systems used in its construction. The superstructure of the house is CLT, clad in a sweet chestnut timber façade. A ground-source heat pump, rainwater recycling and high levels of insulation further reduce the impact of the house on the environment.



Section

© Chris Wright for Living Architecture

2010

Residential (Private)

DUNE HOUSE

Living Architecture

LOCATION
Thorpeness, Suffolk

HEIGHT / STOREYS
26 ft (7.8 m) / 2 storeys

CONSTRUCTION COST
Undisclosed

ARCHITECT
Jarmund Vigsnaes / Mole Architects

STRUCTURAL ENGINEER
engineersHRW (formerly Jane Wernick Associates)

TIMBER ENGINEER
Eurban

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Schilliger Holz

MAIN CONTRACTOR
Willow Builders

TIMBER VOLUME
2,100 ft^3 (60 m^3)

TIMBER ASSEMBLY
1 week

OVERALL CONSTRUCTION
48 weeks

STRUCTURE TYPE
Hybrid

EMBODIED CARBON WITHIN TIMBER*
-38 tons (-35 tonnes) CO_2e

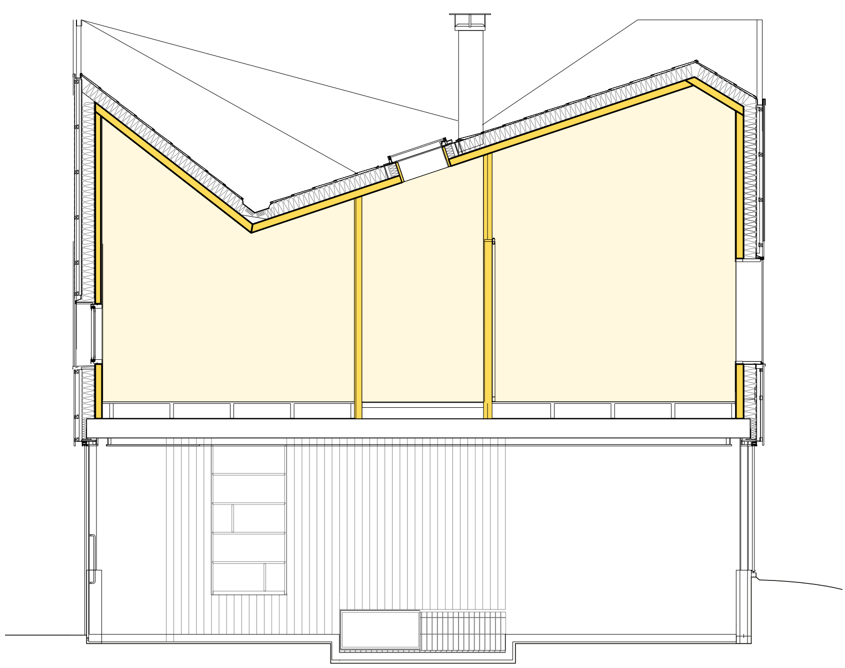
CLT FACT
CLT construction was unaffected by the strong North Sea winds

The house, designed for use as a holiday home, is situated on the Suffolk coast overlooking the sea. Relating to the typical British seaside strip of houses, the roofscape, with an eclectic range of pitches and dormer windows, brings to mind a romantic memory of holidays at bed and breakfasts while traveling through the UK.

The building is designed to be both a refuge against the North Sea, and a beach-side house open to the sandy dunes. The architecture of the ground floor is quite distinct from that of the upper storey. At ground level the open plan living area and terraces are set into the dunes which provide protection from the strong winds. Sliding doors at the corners bring the outside in, and the glazed walls allow for wide views and emphasize the floating appearance of the top floor.

While the materiality of the ground floor; concrete, glass and aluminum, relates to the mass of the ground, the upper floor, which houses four bedrooms, is a CLT construction exposed internally with dark cladding externally reminiscent of existing gables and sheds found within the area. The use of CLT facilitated the construction of the elaborate roof.

A striking and structurally complex house, the load of the upper floor is supported by a reinforced cantilevered concrete slab.



Section

© Ioana Marinescu © Ioana Marinescu

© Karakusevic Carson Architects

2011

Residential

BRIDPORT HOUSE

Hackney Council

LOCATION
London Borough of Hackney

HEIGHT / STOREYS
84 ft (25.6 m) / 5-8 storeys

CONSTRUCTION COST
£6 million

ARCHITECT
Karakusevic Carson Architects

STRUCTURAL ENGINEER
Peter Brett Associates

TIMBER ENGINEER
Eurban

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Stora Enso

MAIN CONTRACTOR
Willmott Dixon

TIMBER VOLUME
55,700 ft³ (1,576 m³)

TIMBER ASSEMBLY
12 weeks

OVERALL CONSTRUCTION
56 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-988 tons (-896 tonnes) CO_2e

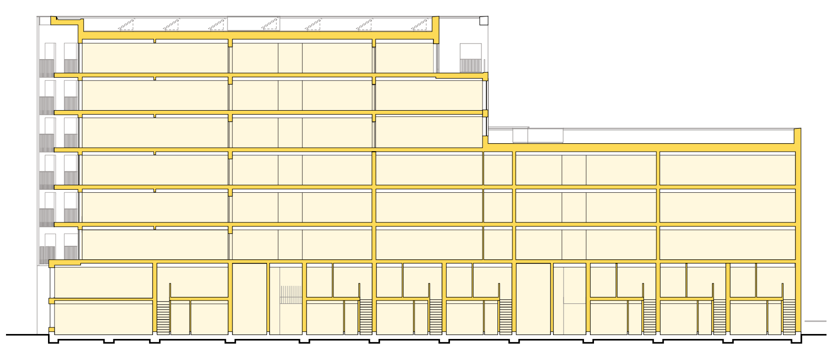
CLT FACT
First multi storey building to use CLT from the ground up

Bridport House is the first phase of the wider Colville Estate Regeneration program which will replace 438 existing homes with over 900 new residences over approximately 20 years.

The building is designed as an eight and five storey urban block, on a narrow and constrained site, replacing a 1960s building that had turned its back on the street. The new Bridport House creates a street frontage onto the refurbished Shoreditch Park and starts to define the emerging street pattern of the masterplan.

One of London's main drainage tunnels runs directly underneath the building meaning that little extra weight could be exerted while the capacity of the block had to be doubled from 21 to 41 new homes. CLT offered a solution, the lightweight quality of timber allowing for twice as many units as the previous block to be built over the large Victorian sewer below. The structure was designed so that the load-bearing CLT panels are placed in a variety of positions on each floor, spreading the load.

The use of CLT for the structure also guaranteed the speed of construction which was essential to achieve the ambitious hand-over date to meet the Homes and Communities Agency's strict funding rules.



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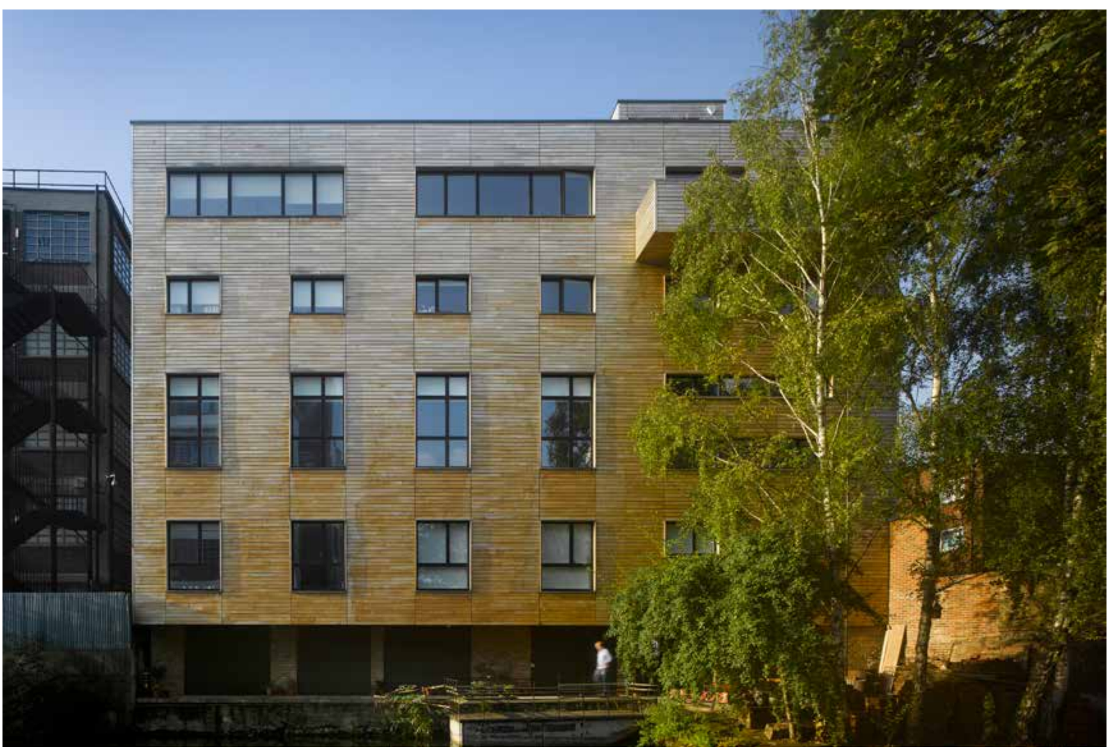


© Will Pryce

2012

Residential

WHITMORE ROAD

Whitmore Road LLP

LOCATION
London Borough of Hackney

HEIGHT / STOREYS
67 ft (20.5 m) / 7 storeys

CONSTRUCTION COST
£2 million

ARCHITECT
Waugh Thistleton Architects

STRUCTURAL ENGINEER
Akera Engineers

TIMBER ENGINEER
KLH UK

TIMBER CONTRACTOR
KLH UK

TIMBER MANUFACTURER
KLH Massivholz

MAIN CONTRACTOR
Jerram Falkus

TIMBER VOLUME
17,600 ft^3 (499 m^3)

TIMBER ASSEMBLY
5 weeks

OVERALL CONSTRUCTION
104 weeks

STRUCTURE TYPE
Pure Timber

EMBODIED CARBON WITHIN TIMBER*
-310 tons (-281 tonnes) CO_2e

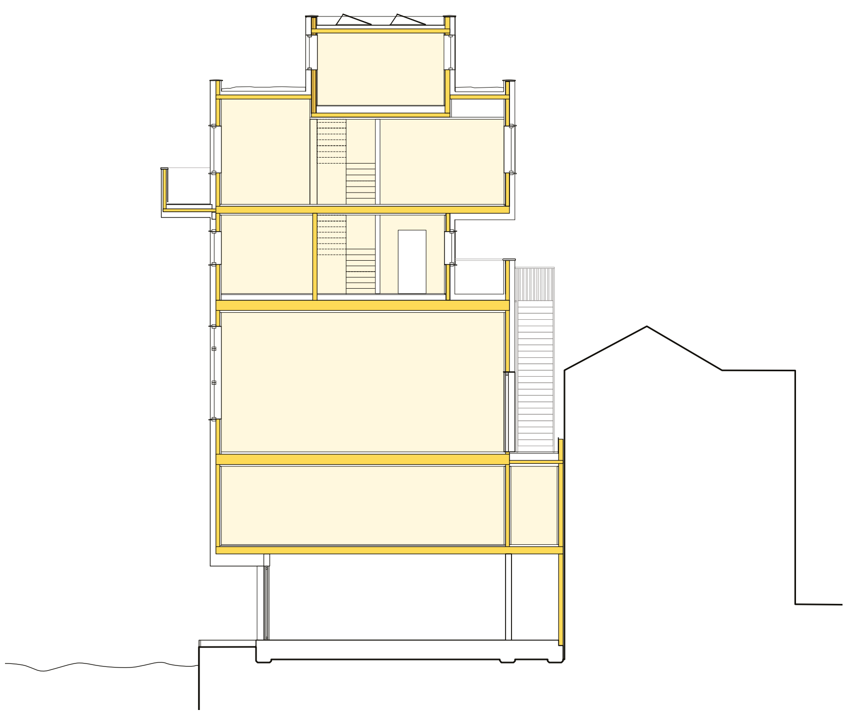
CLT FACT
Timber walls between the flats act as giant trusses above the studio

This mixed use building is located adjacent to the Whitmore Road Bridge over Regent's Canal. It provides the four-client co-operative with two floors of office space, a double-height photographic studio and three triplex apartments at the top of the building that open onto generous roof terraces overlooking the canal.

CLT was the obvious structural solution for this tight urban site. The building footprint extends over almost the entire site area, bounded on two sides by buildings, and a third by the canal. It was craned into place directly from the street in only 5 weeks.

The CLT structure sits on a concrete lower ground floor which acts as a plinth. At the centre of the building, the double height studio spans 30ft and stretches to 79ft of open column-free space. This was achieved using the party walls above the space as deep beams and the north and south façades as giant trusses. Glulam beams on the north façade help spread the loads down this elevation and minimize deflection.

The building is clad in British sweet chestnut, a material traditionally used to clad barns. It is a robust, stable timber which is lightweight, strong and durable. It is less prone to movement, distortion or splitting than other timber species. Similar in color to oak, it has weathered to a natural silver color over time.



Section

© Alex de Rijke / dRMM

2013

Residential (Private)

WOODBLOCK HOUSE

Richard Woods & Jess Spanyol

LOCATION
London Borough of Tower Hamlets

HEIGHT / STOREYS
39 ft (12 m) / 3 storeys

CONSTRUCTION COST
Undisclosed

ARCHITECT
dRMM

STRUCTURAL ENGINEER
Timber First

TIMBER ENGINEER
Timber First/Züblin Timber

TIMBER CONTRACTOR
Züblin Timber (formerly Finnforest Merk)

TIMBER MANUFACTURER
Züblin Timber (formerly Finnforest Merk)

MAIN CONTRACTOR
Cape Construction

TIMBER VOLUME
4,300 ft^3 (121 m^3)

TIMBER ASSEMBLY
2 weeks

OVERALL CONSTRUCTION
34 weeks

STRUCTURE TYPE
Pure CLT

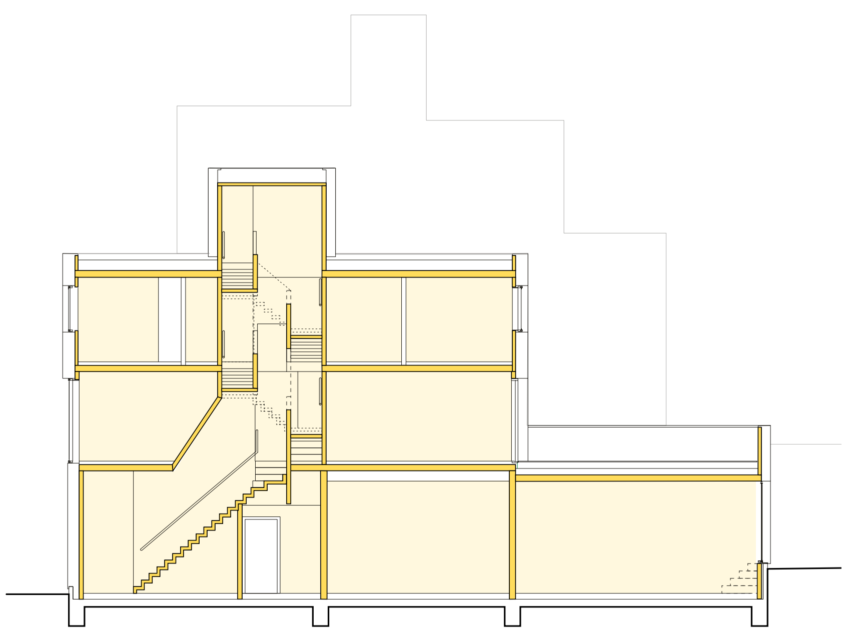
EMBODIED CARBON WITHIN TIMBER*
-76 tons (-69 tonnes) CO_2e

CLT FACT
One of the first all timber houses built in central London since the 1666 Great Fire

Artist Richard Woods approached dRMM with the desire to create a studio, office and home for his family entirely out of wood. Collaboration between the architect and client has resulted in a simple design with both the aesthetic and structural materiality of the house defined by timber.

The house is formed of two cuboid structures resting atop one another. A large workshop and printing studio space occupy the ground floor at a north-facing incline, with separate south-facing living accommodation stacked above. To demarcate the public and private spaces of the building, the studio is clad in unpainted, vertically aligned larch, whilst the south-facing home on the upper floors is identified by horizontal strips of painted plywood. Woods' signature cartoon-esque, brightly-painted wood textile print is used on the plywood façade, and to adorn the internal staircase that extends through the central elevation. These bright, primary hues create a striking contrast with the interior finish of exposed CLT.

Both client and architect were attracted to timber due to its environmental credentials and aesthetic characteristics. Nestled between its neighboring buildings of brick and concrete, Woodblock House demonstrates the potential of CLT infill within an urban residential setting.



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© Paul Riddle

2013

Residential (Private)

SUSSEX HOUSE

Private Client

LOCATION
South Downs, Sussex

HEIGHT / STOREYS
21 ft (6.5 m) / 2 storeys

CONSTRUCTION COST
Undisclosed

ARCHITECT
Wilkinson King

STRUCTURAL ENGINEER
Packman Lucas

TIMBER ENGINEER
Pryce & Myers / KLH UK

TIMBER CONTRACTOR
KLH UK

TIMBER MANUFACTURER
KLH Massivholz

MAIN CONTRACTOR
Westridge Construction

TIMBER VOLUME
2,300 ft^3 (65 m^3)

TIMBER ASSEMBLY
2 weeks

OVERALL CONSTRUCTION
78 weeks

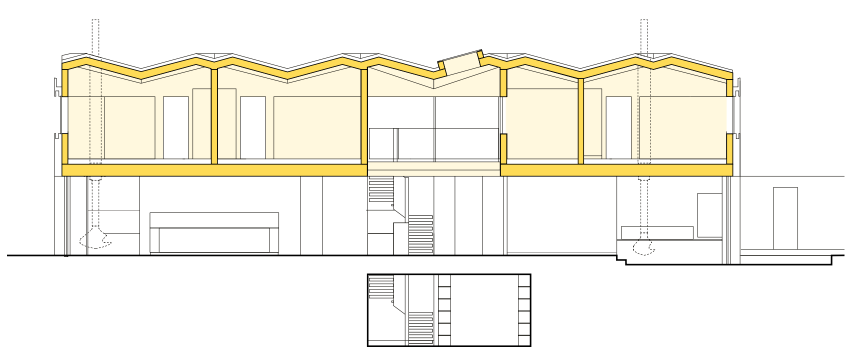
This house is inspired by its rural context and exceptional position overlooking the South Downs. The building is conceived as a series of layers, which echo the horizontality of the meadows and hills as they recede into the distance.

The ground floor is glazed giving panoramic views from the living spaces and can be fully opened up to access the external terraces. The first floor overhangs to provide summer shading. A double height reception space, with exposed CLT walls and ceiling, connects the two floors.

The first floor and roof are assembled from 143 CLT panels. The roof form is made from a series of tilted triangular planes, forming a folded, undulating surface mimicking the distant hills. CLT presented itself as the most structurally efficient and lowest cost option to achieve the spans required.

The internal timber surfaces are exposed bringing a warm, tactile quality to the bedrooms and circulation spaces and providing a harmony between the house and its environs.

The first floor is clad in cedar, weathering to match the color of the surrounding trees. Inline louvered shutters are concealed within the timber façade to prevent summer heat gain from the south facing windows.

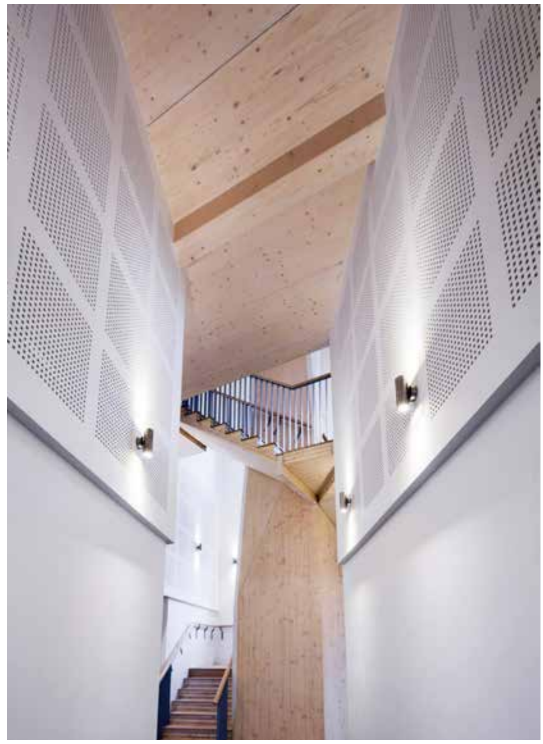


Section

STRUCTURE TYPE
Hybrid

EMBODIED CARBON WITHIN TIMBER*
-39 tons (-36 tonnes) CO_2e

CLT FACT
CLT chosen for ease and low cost of forming complex geometric roof



© Peter Guenzel

2014

Residential

MAZARIN HOUSE

KTN Group

LOCATION
London Borough of Redbridge

HEIGHT / STOREYS
35 ft (10.8 m) / 4 storeys

CONSTRUCTION COST
Undisclosed

ARCHITECT
Arboreal Architecture

STRUCTURAL ENGINEER
Structure Workshop

TIMBER ENGINEER
KLH UK

TIMBER CONTRACTOR
KLH UK

TIMBER MANUFACTURER
KLH Massivholz

MAIN CONTRACTOR
Hutton Group

TIMBER VOLUME
8,500 ft³ (242 m³)

TIMBER ASSEMBLY
5.5 weeks

OVERALL CONSTRUCTION
53 weeks

STRUCTURE TYPE
Pure CLT

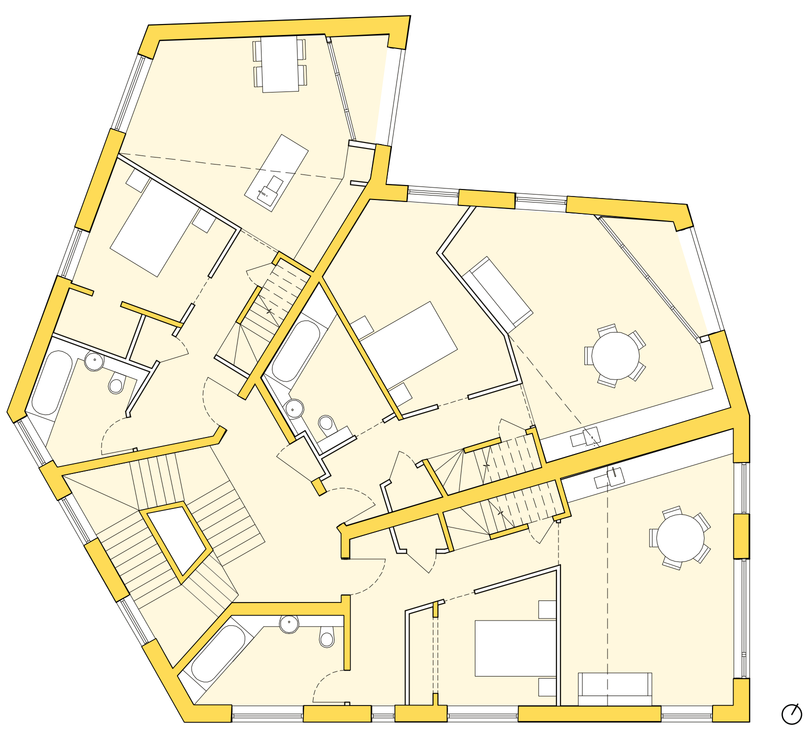
EMBODIED CARBON WITHIN TIMBER*
-149 tons (-135 tonnes) CO_2e

CLT FACT
Digital fabrication allowed for non-orthogonal geometries

Mazarin House is a block of 6 two-bedroom flats in Woodford, East London. The local area comprises detached 1930s homes and 1970s blocks of flats. In response to this mixed urban setting the building was designed as a hybrid between a block of flats and a detached townhouse. This was achieved by combining the density of a block of flats with the massing and proportions of a detached house. The width of the front façade was matched to the adjacent houses and the roof profile echoed the double-bay fronted properties nearby. Four storeys of accommodation were built on a site where only three had previously been possible, whilst the mass of the building was sculpted to respond to allow light and views to reach neighbors.

To optimize the available space, light and views a non-orthogonal geometry was used. Without the restriction of designing only in right angles the building could respond more sensitively to its constraints. All 6 flats achieved south-facing, double-height living spaces and generous balconies.

The non-orthogonal design was made possible by the CLT construction system. The CLT panels form the walls, floors and roof and were cut by computer numerical control (CNC) directly from a 3D computer model. This digital fabrication allowed the many complex angles to be easily constructed on site from a precise kit of parts.



Second Floor Plan

© David Grindley Architects

2014

Residential (Private)

NURSES COTTAGE

Jim Morrison & Jenny Melton

LOCATION
Milton Keynes, Buckinghamshire

HEIGHT / STOREYS
10 ft (3.2 m) / 1 storey

CONSTRUCTION COST
£150,000

ARCHITECT
David Grindley Architects

STRUCTURAL ENGINEER
KMG Tapsell Wade

TIMBER ENGINEER
KMG Tapsell Wade

TIMBER CONTRACTOR
KLH UK

TIMBER MANUFACTURER
KLH Massivholz

MAIN CONTRACTOR
Richard Lyons

TIMBER VOLUME
1,000 ft^3 (29 m^3)

TIMBER ASSEMBLY
3 days

OVERALL CONSTRUCTION
52 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-17 tons (-16 tonnes) CO_2e

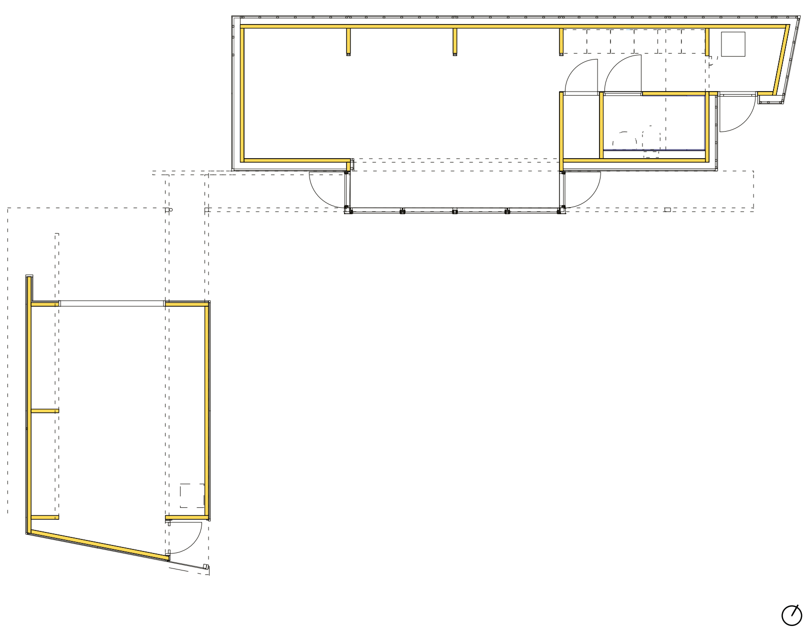
CLT FACT
Client inspired to use CLT after seeing it at the architect's offices

The scheme was conceived as an invisible building disguised as a site boundary adjacent to a listed thatched roof cottage. The new garden room and workshop is set in the curtilage of the Grade II listed Nurses Cottage in the Milton Keynes Village conservation area. Designed to respect the setting of the listed building, the new home was deliberately kept to a single storey with a low pitched green roof.

The building is comprised of two single-storey wings articulated in an 'L' shape courtyard arrangement. In conjunction with the existing cottage this plan forms a new private garden at its centre. The design is clearly articulated into its constituent elements: enclosure; floating roof and glazed colonnade.

The principal material used in the construction of the building is CLT, which is exposed internally and covered with a clear, white finish. The glazed clerestory between the roof and outer enclosing wall reflects light onto the exposed CLT roof panels.

Externally, the building is clad in heat-treated timber weather boarding with an aluminium coping. A planted sedum roof provides thermal mass and attenuation to storm water, while heat is provided via a ground-source pump.



Ground Floor Plan


© Dennis Gilbert


© Mark Polyblank


© Dennis Gilbert

2014

Residential

KINGSGATE HOUSE

De Vere Gardens / Catalyst Housing

LOCATION
Royal Borough of Kensington & Chelsea

HEIGHT / STOREYS
75 ft (23 m) / 7 storeys

CONSTRUCTION COST
£9.6 million

ARCHITECT
Horden Cherry Lee Architects

STRUCTURAL ENGINEER
Price & Myers

TIMBER ENGINEER
KLH UK

TIMBER CONTRACTOR
KLH UK

TIMBER MANUFACTURER
KLH Massivholz

MAIN CONTRACTOR
Willmott Dixon

TIMBER VOLUME
38,600 ft^3 (1,092 m^3)

TIMBER ASSEMBLY
12 weeks

OVERALL CONSTRUCTION
78 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
679 tons (-616 tonnes) CO_2e

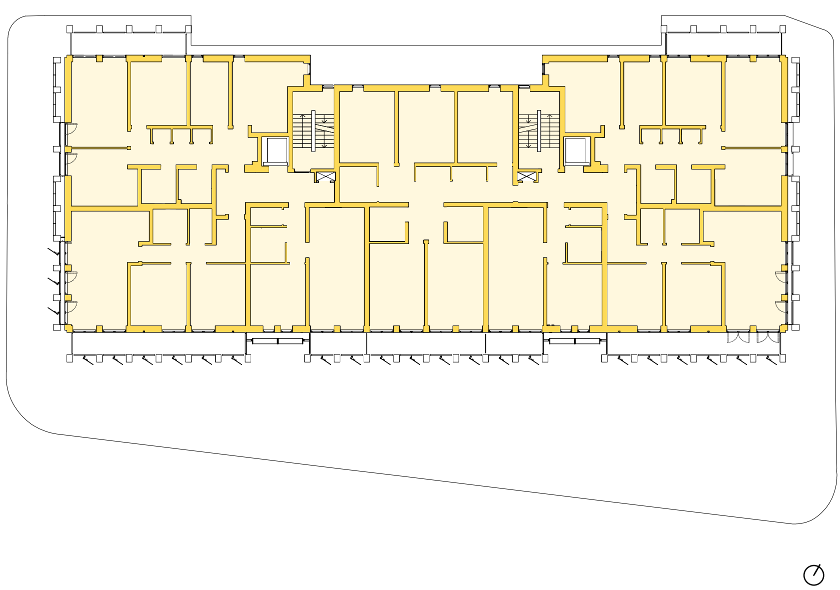
CLT FACT
First major building to be PEFC certified

Kingsgate House is a modern design for affordable housing that integrates its sustainable and environmental responsibilities into the architecture. The building provides 43 new homes on a prominent site in Kensington.

The design form, proportions and column spacing were established from careful analysis of the local historic context, a conservation area made up largely of stuccoed Victorian estates.

The façade is formed of vertically integrated solar shutters that respond to orientation and provide privacy for residents. The multi-toned, phosphorescent green of the PVC cells recalls the colors of the surrounding trees. Behind the shutters each apartment has its own recessed balcony, which provide external space that is not exposed to the heavy traffic on the adjacent main road. Energy created by the PV panels is fed back into the grid.

Selected for its environmental credentials, the use of CLT in this project enabled the reuse of existing foundations on site due to the reduction in weight as compared to a traditional structure, saving time and money. Kingsgate House was the first major building project to be PEFC certified demonstrating that all the timber used was both sustainable and ethically sourced.



Typical Floor Plan in Context

© Jack Hobhouse

2015

Residential

WENLOCK CROSS

Regal Homes

LOCATION
London Borough of Hackney

HEIGHT / STOREYS
110 ft (33.5 m) / 10 storeys

CONSTRUCTION COST
£10.5 million

ARCHITECT
Hawkins\Brown

STRUCTURAL ENGINEER
Pringuer-James

TIMBER ENGINEER
Engenuiti

TIMBER CONTRACTOR
B & K Structures

TIMBER MANUFACTURER
Binderholz

MAIN CONTRACTOR
Eurobuild Properties

TIMBER VOLUME
46,400 ft^3 (1,313 m^3)

TIMBER ASSEMBLY
30 weeks

OVERALL CONSTRUCTION
108 weeks

STRUCTURE TYPE
Hybrid

EMBODIED CARBON WITHIN TIMBER*
-788 tons (-715 tonnes) CO_2e

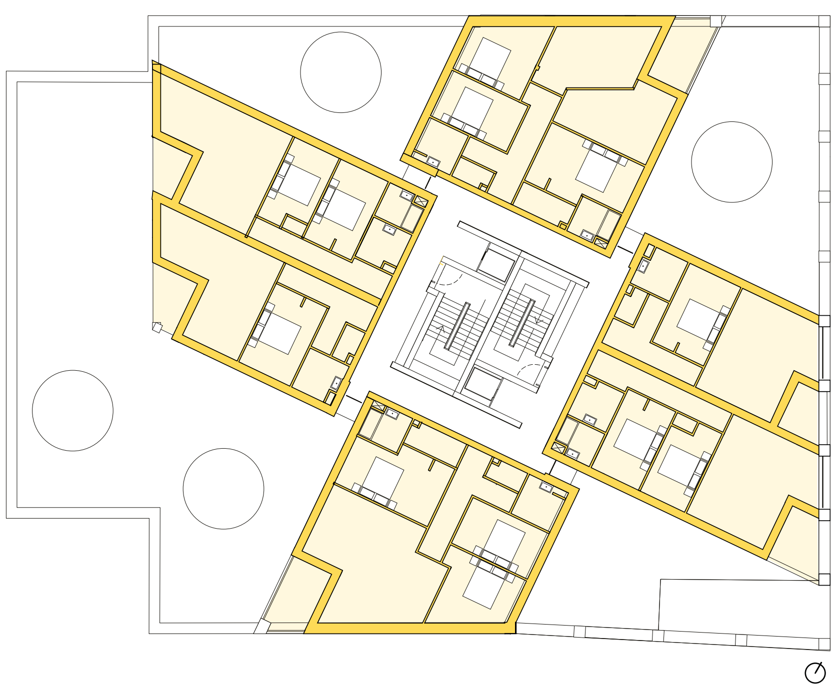
CLT FACT
Hackney's timber first initiative encouraged investigation into CLT

Wenlock Cross alters the traditional housing block to provide each apartment with daylight, beautiful views and external space on a tight urban site.

The twisted cruciform plan creates four elevations with direct visual connections to the City of London. The irregular, skewed cruciform ensures that all apartments have dual or triple aspect views with generous terraces, good natural ventilation, and avoids views to interior courtyards or lightwells. The angular plan also reduces residents' perception of density from within the apartments. Surrounding the street-facing side of the block is a skeletal brick grid that gives the large external terraces a sense of privacy, and creates a striking silhouette when viewed from the street.

A hybrid CLT and steel structure proved to be the most efficient way to realize this unique 10-storey building and uses the inherent strengths of each material to rationalize the main superstructure. The CLT elevations are clad in slatted western red cedar, whilst along the Wenlock Road elevation, a dark brick screen completes the street elevation making reference to the light industrial character of the conservation area.

Hackney Councils's Timber First agenda encouraged the choice of CLT as the structural solution for this scheme. Upon its completion, Wenlock Cross was the tallest hybrid CLT building in the UK.



Second Floor Plan

© Tim Soar

2016

Residential

BARRETTS GROVE

Nick Grant

LOCATION
London Borough of Hackney

HEIGHT / STOREYS
59 ft (18 m) / 5 storeys

CONSTRUCTION COST
£1.27 million

ARCHITECT
Groupwork + Amin Taha

STRUCTURAL ENGINEER
Webb Yates Engineers

TIMBER ENGINEER
Egoin

TIMBER CONTRACTOR
Egoin

TIMBER MANUFACTURER
Egoin

MAIN CONTRACTOR
Ecore Construction

TIMBER VOLUME
8,800 ft³ (250 m³)

TIMBER ASSEMBLY
2 weeks

OVERALL CONSTRUCTION
52 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-158 tons (-144 tonnes) CO_2e

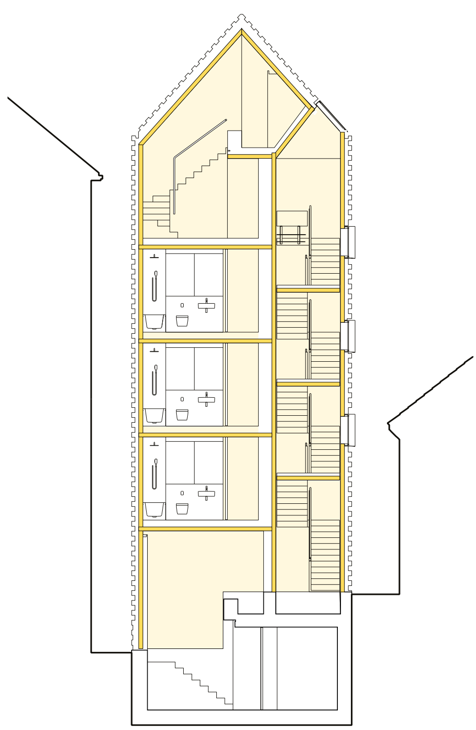
CLT FACT
£30,000 saving per flat

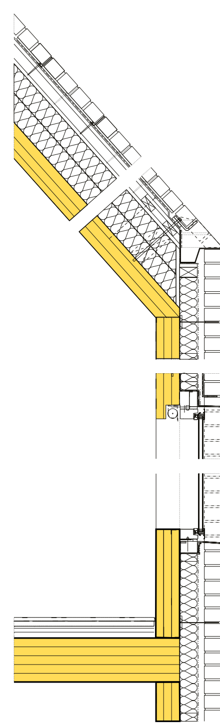
Accommodating six flats on a site between a Victorian Terrace and Edwardian School, the scheme echoes both the tall gables of the school and standalone villa typology of the terrace. The six-storey structure is made of load-bearing CLT panels, spanning up to 20ft. The roof is also solid CLT panels, carefully balanced against each other to create an open loft space within a traditionally pitched roof.

By positioning all services and build-ups on top of the floor slab, it has been possible to expose the CLT structure on all internal walls and ceilings allowing the material finish to provide the domestic character of the spaces. In addition to exposing its planar surface the cut edge is also left visible in order to describe its own make-up, structural depth and to reinforce if not reassure that the timber wall and ceiling finishes are not an effect.

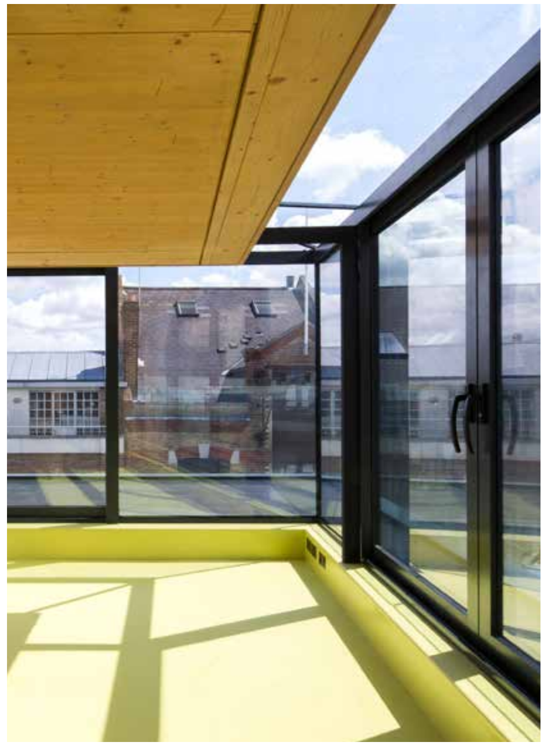
Insulation with vapour barrier and protecting sheeting are applied to the outside face before a self-supporting brick rain-screen completes the exterior thermal and protective overcoat.

Using CLT as structure and finish removed the need for plasterboarded walls, suspended ceilings, cornices, skirtings, tiling and paint; reducing by 15% the embodied carbon of the building, and saving approximately £30,000 per flat.





Section and Detail



© Agnese Sanvito

2015

Residential (Private)

142 BERMONDSEY STREET

Private Client

LOCATION
London Borough of Southwark

HEIGHT / STOREYS
39 ft (12 m) /4 storeys

CONSTRUCTION COST
Undisclosed

ARCHITECT
Hampson Williams

STRUCTURAL ENGINEER
Webb Yates

TIMBER ENGINEER
Eurban

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Stora Enso

MAIN CONTRACTOR
Cityline Construction

TIMBER VOLUME
1,900 ft^3 (55 m^3)

TIMBER ASSEMBLY
2 weeks

OVERALL CONSTRUCTION
52 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-35 tons (-31 tonnes) CO_2e

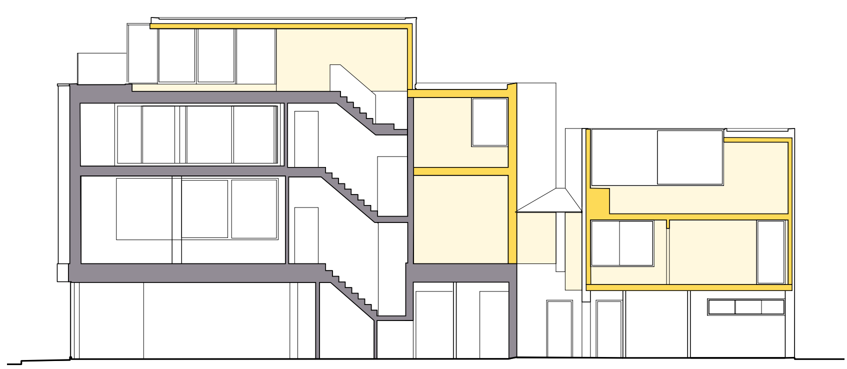
CLT FACT
Lightweight material eliminated need for additional foundations

Hampson Williams were commissioned to refurbish and extend the client's existing home: a post-war building located in the Bermondsey Street Conservation area, providing a mix of residential, commercial and mixed use units. The concept was to create a bookend to the adjacent Georgian terrace, wrapping the form around the corner. Using the existing building as a starting point, large windows were introduced giving open views across the White Cube courtyard and providing south-facing sunlight.

Externally there is a simple, industrial-style box formed of planes with robust materials and clean lines retaining the white rendered aesthetic of the existing building as a base material. Large windows, placed at irregular intervals across the exterior, are defined by thick, black borders creating a striking street front façade.

These clean lines and industrial materials are continued internally with the exposed CLT timber structure bringing a softer residential feel and adding warmth to the spaces.

CLT was selected primarily to reduce costs – the lightweight material not requiring additional foundations. The speed of construction also lent itself to this tight urban site, limiting road closures and storage of materials on site.



Section

© Alex de Rijke / dRMM

2015

Residential

TRAFALGAR PLACE

Lendlease

LOCATION
London Borough of Southwark

HEIGHT / STOREYS
118 ft (36 m) / 4 - 10 storeys

CONSTRUCTION COST
Undisclosed

ARCHITECT
dRMM

STRUCTURAL ENGINEER
Robert Bird Group

TIMBER ENGINEER
Eurban

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Stora Enso

MAIN CONTRACTOR
Lendlease

TIMBER VOLUME
26,500 ft^3 (750 m^3)

TIMBER ASSEMBLY
6 weeks

OVERALL CONSTRUCTION
78 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-467 tons (-424 tonnes) CO_2e

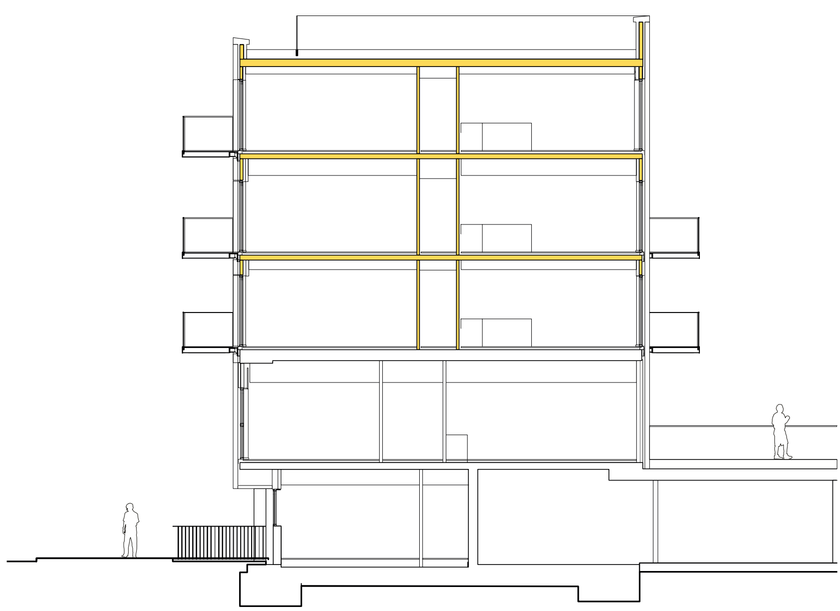
CLT FACT
Building CLT alongside traditional methods can reduce the benefits

Elephant and Castle suffered huge damage during WWII. The buildings that went up in the 1960s were often of poor quality; their huge structures created a place that found it hard to adapt and grow. The masterplan for the redevelopment of the Heygate Estate aims to restore this area to its former glory as a thriving, desirable place to live and visit.

Trafalgar Place is the first phase of this redevelopment and comprises 235 homes. Steering away from the alienating size of previous buildings the scheme provides variety through scale, with a mixture of mini-towers, apartment blocks and townhouses. Each apartment has been designed from the inside out, maximizing light and space, and all have either a garden, balcony or roof terrace.

Conceived as an opportunity for the client to test CLT as a long-term solution to building housing within the UK market, the two timber blocks are constructed principally of CLT, comprising CLT stair and lift shafts for stability and load-bearing façade and internal party walls. Load-bearing partition walls within apartments were avoided, with 21ft spans typically achieved allowing for future flexibility.

Whilst the quantum of timber is not the most significant, this project is a step-change in the delivery of large residential housing schemes.



Section

2015

Residential

COBALT PLACE

Lendlease

LOCATION
London Borough of Wandsworth

HEIGHT / STOREYS
63 ft (19.3 m) / 6 storeys

CONSTRUCTION COST
£13 million

ARCHITECT
Allford Hall Monaghan Morris

STRUCTURAL ENGINEER
Walsh Associates

TIMBER ENGINEER
Eurban

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Stora Enso

MAIN CONTRACTOR
Lendlease

TIMBER VOLUME
90,900 ft³ (2,575 m³)

TIMBER ASSEMBLY
12 weeks

OVERALL CONSTRUCTION
69 weeks

STRUCTURE TYPE
Pure Timber

EMBODIED CARBON WITHIN TIMBER*
-1,607 tons (-1,458 tonnes) CO_2e

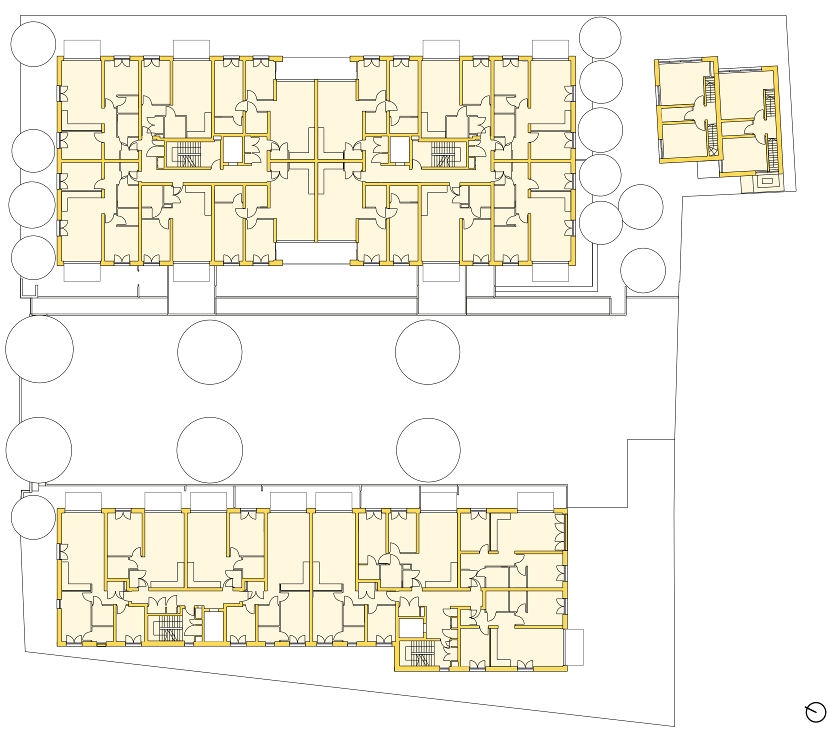
CLT FACT
Client request to change from concrete to CLT

Cobalt Place is an enabling scheme, part funding a new school on the wider masterplan on the former Salesian College site. The scheme comprises 102 apartments split across two 5-6 storey buildings and two separate townhouses. The buildings are arranged to form a residential quarter with a central courtyard, opening up new views to the neighboring Sacred Heart church and increasing both visual and physical permeability.

The blocks are faced with two types of brick which recalls the Victorian houses of the surrounding area. Each storey is expressed with stack bond banding to add both a finer grain and improved legibility to the elevations.

Internally, communal areas are defined by expanses of exposed fair-faced timber panels, revealing the structure as an aesthetic element, bringing natural warmth to the contemporary design of the new homes.

Initially designed as a concrete framed scheme, the decision to change the scheme to CLT was driven by the client. Chosen for its sound structural properties, construction efficiency and low environmental impact, the CLT structure is one part of the client's wider sustainability agenda.



First Floor Plan in Context

© Peter Cook

2015

Residential (Education)

ST CLARE'S COLLEGE

St Clare's College

LOCATION
Oxford, Oxfordshire

HEIGHT / STOREYS
42 ft (12.8 m) / 3 storeys

CONSTRUCTION COST
£4.5 million

ARCHITECT
Hodder + Partners

STRUCTURAL ENGINEER
Thornton Tomasetti

TIMBER ENGINEER
Eurban

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Hasslacher

MAIN CONTRACTOR
Benfield and Loxley

TIMBER VOLUME
11,400 ft^3 (323 m^3)

TIMBER ASSEMBLY
12 weeks

OVERALL CONSTRUCTION
66 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-198 tons (-179 tonnes) CO_2e

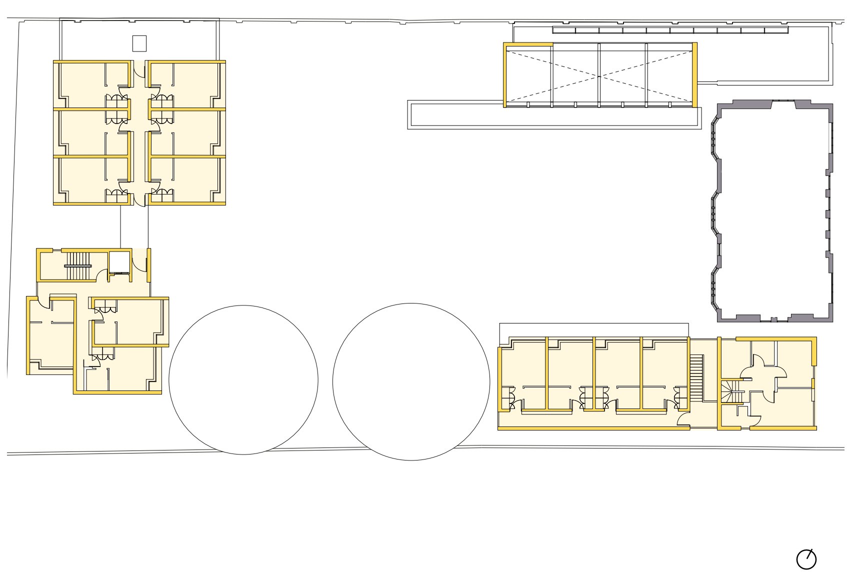
CLT FACT
Proportions of the study rooms suited CLT perfectly

This project comprises five individual buildings woven between existing mature trees, with a restored Grade II listed villa at its head. Linked by walkways the buildings create a quadrangle reminiscent of the traditional Oxford college layout.

The villa is flanked by a new warden's house, and a single storey timber lined arts studio. Opposite the villa is a pair of linked two and three storey buildings housing student accommodation. The quadrangle is completed to the south by another 'pavilion' of single and double study rooms.

All five buildings have a CLT structure and are clad with a rainscreen of vertical oak boards. The use of CLT lent itself to the cellular nature of study rooms which is expressed on the façades. The material language seeks to reinforce the notion of pavilions in a garden.

The naturally-ventilated art studio has an oak glulam portal frame which supports the CLT roof and wall panels. Glazed panels and doors between the glulam columns on the south side are protected from the strong sunlight by doors and an oak-clad CLT canopy cantilevers over the walkway, supported by the glulam columns. Continuing beyond the wall of the studio the canopy and the glulam columns create a cloister-like loggia which defines the north side of the quadrangle.



First Floor Plan

© Alex Sarginson

© Alex Sarginson

© Adrian Wolfson

2015

Residential (Private)

LANSDOWNE DRIVE PASSIVHAUS

Bernard Tulkens

LOCATION
London Borough of Hackney

HEIGHT / STOREYS
16 ft (4.9 m) / 2 storeys

CONSTRUCTION COST
£350,000

ARCHITECT
TECTONICS Architects

STRUCTURAL ENGINEER
Michael Hadi Associates

TIMBER ENGINEER
Eurban

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Hasslacher

MAIN CONTRACTOR
N/A

TIMBER VOLUME
900 ft^3 (25 m^3)

TIMBER ASSEMBLY
2 days

OVERALL CONSTRUCTION
46 weeks

STRUCTURE TYPE
Pure CLT

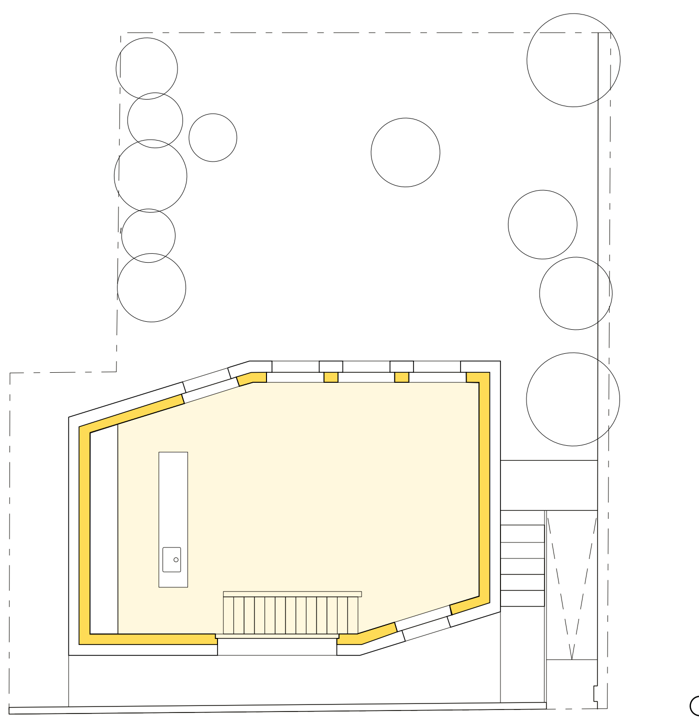
EMBODIED CARBON WITHIN TIMBER*
-15 tons (-14 tonnes) CO_2e

CLT FACT
CLT helped towards achieving Passivhaus status

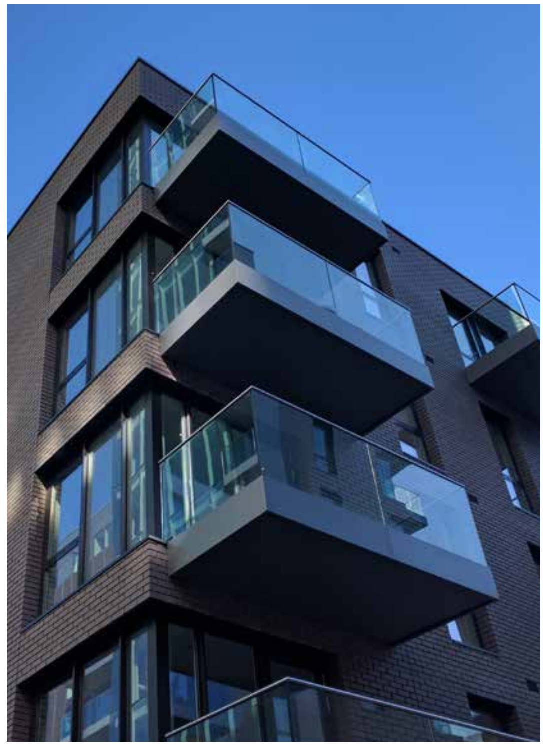
The building is located in a conservation area in East London on an infill garden site amidst four storey Victorian terraced houses. Sitting behind a garden wall along the street, the house is half sunken to remain discreet, a suggestion from the local planning department. From the street the house appears as a low, zinc-clad chamfered volume.

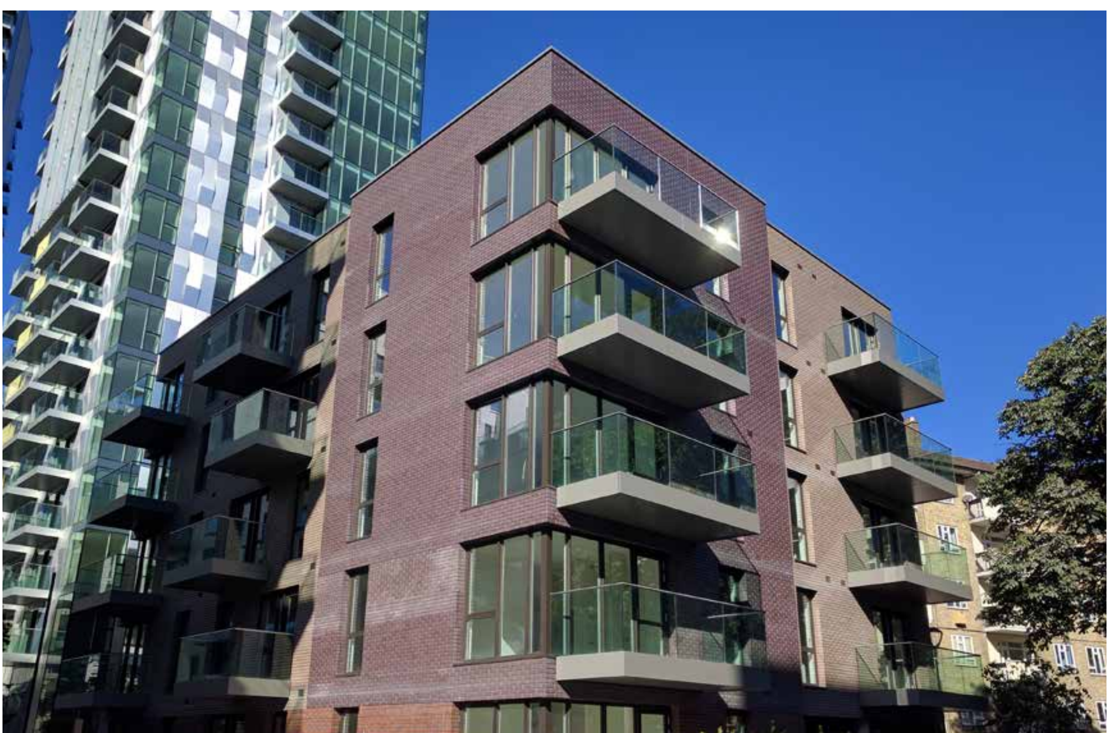
Responding to the context, the objective was to create a building with the generic simplicity, flexibility, light and character found in industrial spaces. The main construction components have been left exposed internally. The structural concrete of the lower ground floor roots the building, while the CLT panels which form the living spaces on the upper level sit alongside the conduits and ducts, providing a simple palette of materials and a very direct sense of the construction.

A modern space made using natural materials, with ultra-low energy requirements, the building was awarded Passivhaus status. It is the first certified Passivhaus in the UK to use CLT and woodfibre insulation construction.



First Floor Plan





2016

Residential

WOODBERRY DOWN

Berkeley Homes

LOCATION
London Borough of Hackney

HEIGHT / STOREYS
51 ft (15.4 m) / 5 storeys

CONSTRUCTION COST
Undisclosed

ARCHITECT
Waugh Thistleton Architects

STRUCTURAL ENGINEER
Eurban

TIMBER ENGINEER
Eurban

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Stora Enso

MAIN CONTRACTOR
Berkeley Homes

TIMBER VOLUME
17,800 ft^3 (503 m^3)

TIMBER ASSEMBLY
5.5 weeks

OVERALL CONSTRUCTION
39 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-313 tons (-284 tonnes) CO_2e

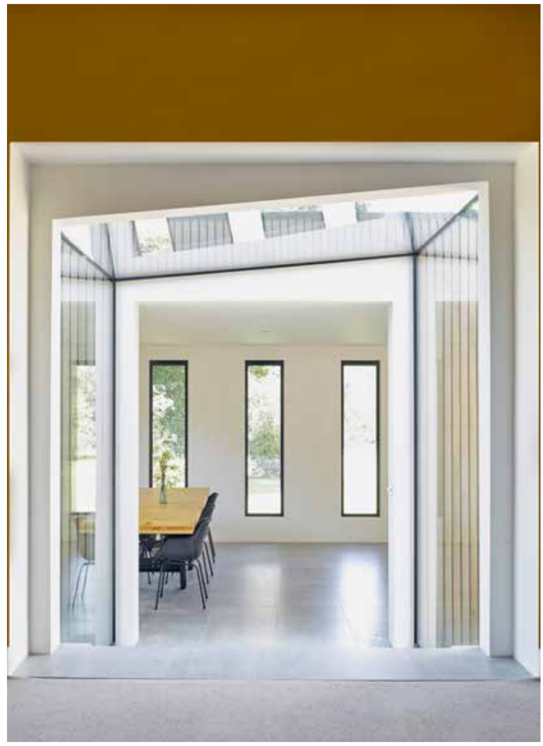
CLT FACT
CLT erected 6.5 weeks quicker than the originally planned concrete frame

The Woodberry Down Estate spans a total of 64 acres, next to the New River and West and East Reservoirs, which total 42 acres of open water, in an area of north-east London which is undergoing significant re-development. The process of demolishing 1,980 homes and rebuilding over 5,500 is scheduled across eight phases over a period of 20 years.

As the first CLT building within the estate development, this is the first venture into CLT construction for Berkeley Homes, one of the UK's largest house builders. The objective was to encourage the wider adoption of CLT construction in both the coming phases of the regeneration, and throughout Berkeley Homes' development portfolio.

Originally designed to be built using a reinforced concrete frame, the decision to change to a CLT structure came at a relatively late stage. Despite this, the layout of this five-storey building was able to remain largely unchanged with internal steel columns replacing the concrete columns to achieve the large openings for the corner windows. The thinner floor build up reduced the height by 3 inches per storey which in turn reduced the quantity of building materials used. The 19 homes were delivered ahead of schedule and achieved higher than anticipated thermal and air tightness performance.

Section



© James Morris

2016

Residential (Private)

HURDLE HOUSE

Private Client

LOCATION
Alresford, Hampshire

HEIGHT / STOREYS
11 ft (3.5 m) / 1 storeys

CONSTRUCTION COST
£250,000

ARCHITECT
Adam Knibb Architects

STRUCTURAL ENGINEER
Eckersley O'Callaghan

TIMBER ENGINEER
KLH UK

TIMBER CONTRACTOR
KLH UK

TIMBER MANUFACTURER
KLH Massivholz

MAIN CONTRACTOR
Gregory Collins

TIMBER VOLUME
1,100 ft^3 (31 m^3)

TIMBER ASSEMBLY
4 days

OVERALL CONSTRUCTION
20 weeks

STRUCTURE TYPE
Pure Timber

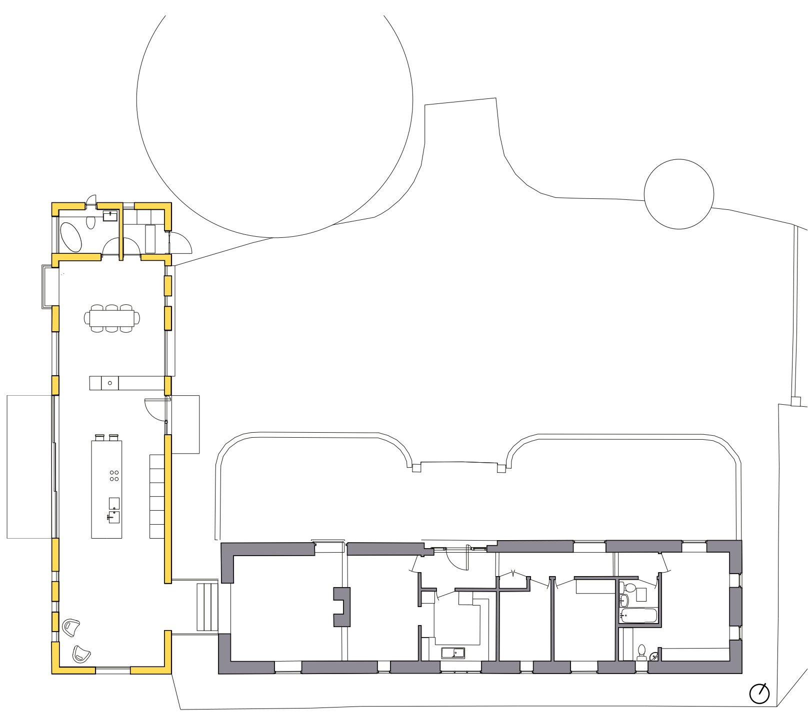
EMBODIED CARBON WITHIN TIMBER*
-19 tons (-17 tonnes) CO_2e

CLT FACT
Timber chosen to tie in with landscape and reduce waste on site

Hurdle House is a Grade II listed barn, constructed in the mid eighteenth-century. The house has a north-south axis with an extensive rear garden and expansive views to the north. The building receives sunlight throughout the day and is overlooked only by the surrounding trees and fields. The contemporary extension aims to provide a social heart to the house harnessing the fantastic views not allowed by the original building.

Set at a 90-degree angle to the original house, a frameless glass space lightly connects the old with the new. Rethinking the movement from public to private areas, the extension uses visual barriers rather than physical blockades to demarcate the spaces that comprise large open plan kitchen, dining area, casual seating and study. Large glass apertures blur the boundaries between the natural surroundings of the property and the interior spaces and the new entrance arrives in the heart of this space, providing direct views into the garden.

Timber was the central component of the project, determining the scale, form and openings and tying the materiality of the building to the expansive landscape that surrounded the existing property. Vertical timber cladding mimics the surrounding trees and provides a contemporary contrast to the existing building.



Ground Floor Plan

© Johan Dehlin

2016

Residential (Education)

COWAN COURT

Churchill College

LOCATION
Cambridge,
Cambridgeshire

HEIGHT / STOREYS
33 ft (10 m) / 3 storeys

CONSTRUCTION COST
£9.22 million

ARCHITECT
6a Architects

STRUCTURAL ENGINEER
Pryce & Myers

TIMBER ENGINEER
Engenuiti

TIMBER CONTRACTOR
B & K Structures

TIMBER MANUFACTURER
Binderholz /
Rubner Holzbau

MAIN CONTRACTOR
SDC

TIMBER VOLUME
11,100 ft^3 (314 m^3)

TIMBER ASSEMBLY
14 weeks

OVERALL CONSTRUCTION
77 weeks

STRUCTURE TYPE
Pure Timber

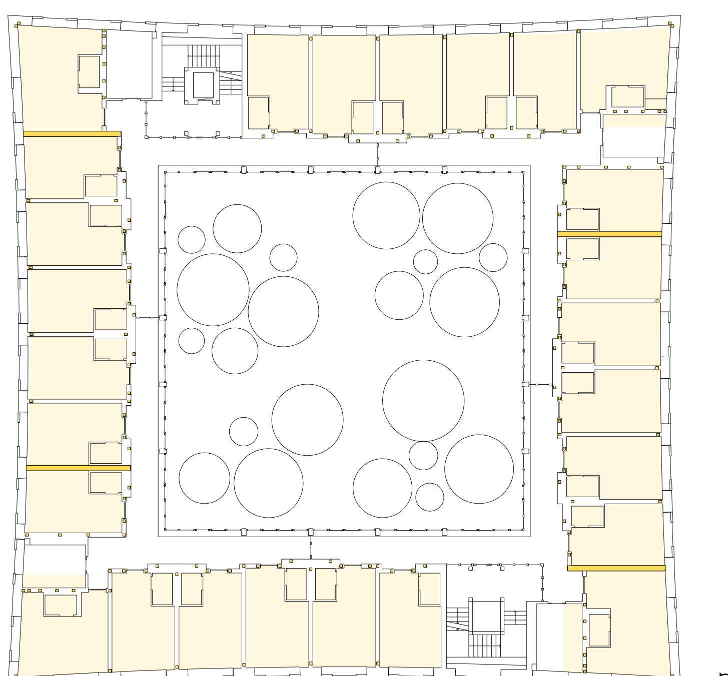
EMBODIED CARBON WITHIN TIMBER*
-191 tons (-173 tonnes) CO_2e

CLT FACT
Engineered timber structure chosen for sustainability credentials

Cowan Court is a 68-room hall of residence and the first completely new court since the college was founded as a memorial to Sir Winston Churchill in the early 1960s. This new court, adjacent to the existing accommodation courts, turns the Brutalism of the original buildings towards the 21st century bringing sustainability, accessibility, landscape and a new approach to communal and private space to the heart of the design.

Cowan Court responds to the original in a contemporary timber construction. In three overhanging floors, the jettying timber cuts recall the concrete bands across the façades of the existing courts. Each of the façades is curved like the entasis of a classical column, and the square windows of the student rooms spiral up and across.

The structure of the building consists of a glulam post and beam frame with CLT floor panels. Each wing is braced by full height CLT or concrete shear walls, with the concrete walls restricted to the two cores. The glulam beams remain exposed in most areas, giving a rhythm and natural depth to the interior. The materiality forms part of an ambitious environmental strategy; passive ventilation, triple glazing and super insulation reduced the amount of energy consumed in construction and in use. Solar electricity and rainwater collection reduce the energy requirements yet further.



First Floor Plan

© Richard Osbourne

2016 Residential (Education)

UEA BLACKDALE

University of East Anglia

LOCATION
Norwich, Norfolk

HEIGHT / STOREYS
71 ft (21.7 m) / 5 storeys

CONSTRUCTION COST
£27.5 million

ARCHITECT
LSI Architects

STRUCTURAL ENGINEER
Ramboll

TIMBER ENGINEER
Ramboll

TIMBER CONTRACTOR
KLH UK

TIMBER MANUFACTURER
KLH Massivholz

MAIN CONTRACTOR
R G Carter

TIMBER VOLUME
128,200 ft^3 (3,930 m^3)

TIMBER ASSEMBLY
17 weeks

OVERALL CONSTRUCTION
62 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-2,242 tons (-2,034 tonnes) CO_2e

CLT FACT
Use of CLT was in line with the University's environmental policy

Set over two blocks this new residential quarter for the university provides 514 new student rooms. The design for both student accommodation blocks, named Hickling House and Barton House, takes inspiration from the distinctive shapes of the 1960s Denys Lasdun Teaching Wall.

The Blackdale student accommodation is a gateway into the university campus. Blocks are clad with pale grey panels, chosen to complement the concrete structures of the original campus, with gold accent cladding on key views. Angled windows project from the façade to obscure views from outside, adding visual interest and a means to channelling light into the building.

The use of CLT was key in supporting the university's environmental policies and reduced the embodied carbon of the construction. It also enabled the tight program to be met with students moving in for the autumn semester.

First Floor Plan in Context

© Tim Crocker

2017

Residential

BACTON LOW RISE (PHASE 1)

Camden Council

LOCATION
London Borough of Camden

HEIGHT / STOREYS
57 ft (17.5 m) / 5 storeys

CONSTRUCTION COST
£18 million

ARCHITECT
Karakusevic Carson Architects

STRUCTURAL ENGINEER
Roltons

TIMBER ENGINEER
Eurban

TIMBER CONTRACTOR
Eurban

TIMBER MANUFACTURER
Stora Enso

MAIN CONTRACTOR
Rydon

TIMBER VOLUME
60,800 ft^3 (1,72 m^3)

TIMBER ASSEMBLY
Block A - 8 weeks
Block B - 10 weeks

OVERALL CONSTRUCTION
90 weeks

STRUCTURE TYPE
Hybrid

EMBODIED CARBON WITHIN TIMBER*
-1,077 tons (-977 tonnes) CO_2e

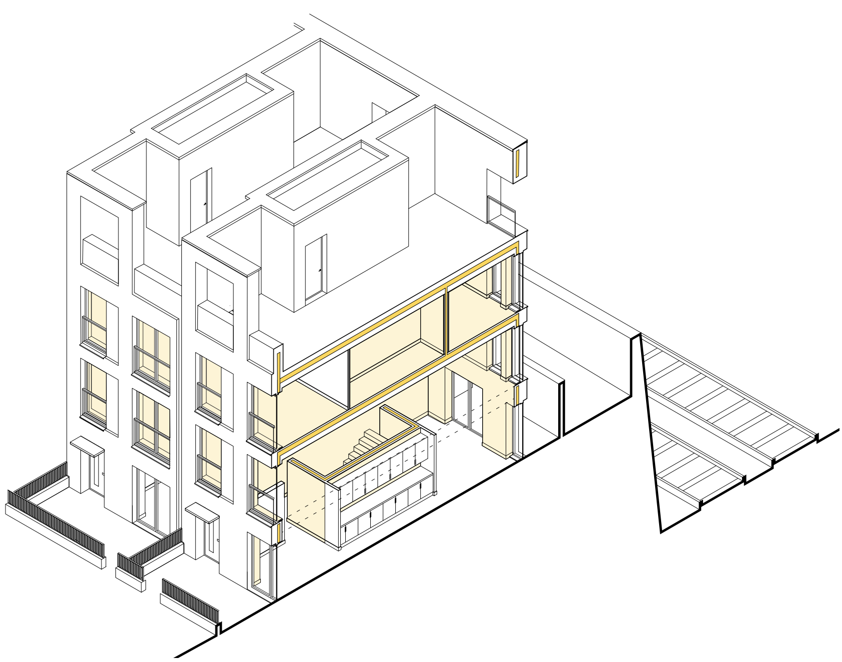
CLT FACT
The light weight reduced number of piles and enabled a complex site

This community-led regeneration project focuses on the transformation of a 1960s estate into a new community of homes for new and existing residents; reconnecting the new neighborhood with the local community.

The 294 unit masterplan achieved planning in March 2013. The first phase started construction in March 2014 and by November 2015 all existing residents had moved into their new homes.

The first phase provided a decant site: a narrow triangle of land next to a high-speed trainline with severe noise and vibration constraints. To counteract this a physical buffer of townhouses and stacked maisonettes was built along the railway. The use of CLT enabled the construction to mitigate the acoustic and vibration impact from the trains, which was very efficient compared to traditional RC frame construction.

Initially concerned that specifying CLT would narrow the field of contractors and reduce the competitive tender, the client's perception was swiftly overcome by the benefits of using CLT on a tight urban site. The frame was quick to install and was slotted and bolted together with very low levels of noise and dust. Fewer piles were required, resulting in less noise and lowering costs. Reduced deliveries meant that the site could run more efficiently and had less impact on the local community.



Townhouse Sectional Axonometric

© Waugh Thistleton

© Daniel Shearling

© Daniel Shearling

2017

Residential

DALSTON WORKS

Regal London

LOCATION
London Borough of Hackney

HEIGHT / STOREYS
111 ft (33.8 m) / 10 storeys

CONSTRUCTION COST
Undisclosed

ARCHITECT
Waugh Thistleton Architects

STRUCTURAL ENGINEER
PJCE

TIMBER ENGINEER
Ramboll

TIMBER CONTRACTOR
B & K Structures

TIMBER MANUFACTURER
Binderholz

MAIN CONTRACTOR
Regal Homes

TIMBER VOLUME
164,200 ft^3 (4,649 m^3)

TIMBER ASSEMBLY
52 weeks

OVERALL CONSTRUCTION
130 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-2,878 tons (-2,611 tonnes) CO_2e

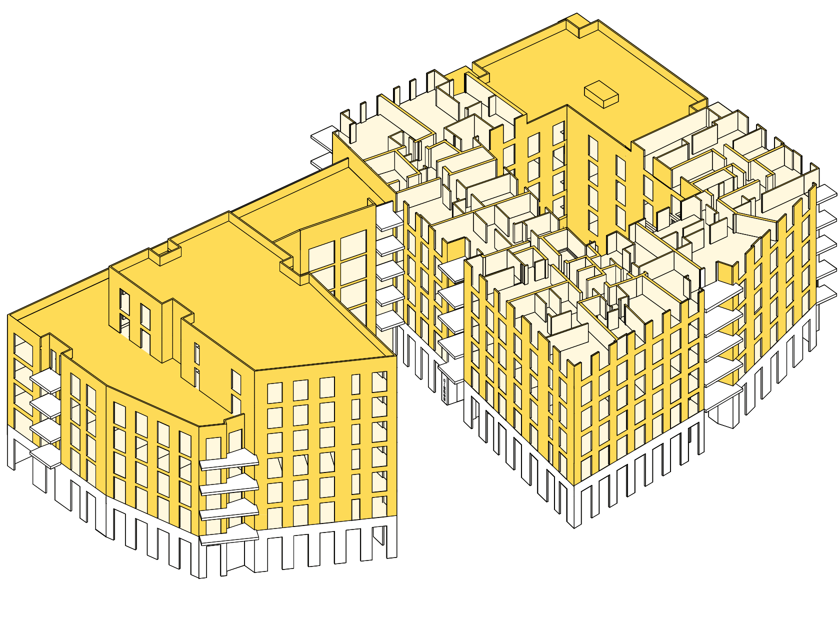
CLT FACT
Delivers 35 more homes than would be possible with a concrete frame

Dalston Works is the world's largest CLT building, delivering 121 new affordable and private (for rent) homes alongside 38,000ft^2 of commercial space.

Designed as a village within a city, the plan is modulated to break down the large site into discernible volumes, orientated to maximize daylight to courtyards and living spaces. A public courtyard activates the existing streetscape, while a second courtyard offers a private, secluded space for residents. The building's intricate brickwork references the surrounding Victorian and Edwardian housing and the detailing of local warehouses, providing a contemporary addition to the local streetscape.

Conceived of and built in solid timber, Dalston Works showcases how CLT can help deliver high-quality, high-density housing without compromising the environment. Constrained by the future Crossrail 2 train line that runs under the site, the CLT weighs a fifth of a comparable concrete structure. This reduced weight combined with the minimal raft foundation enabled the creation of 35 additional homes than would have been otherwise possible in concrete frame.

Rising to 10 storeys at its highest, the CLT structure uses the equivalent of 2,325 trees - around three trees per person living or working in the building.



Sectional Axonometric of CLT

2017

Residential (Private)

CARMARTHEN HOUSE

Amanda & Robert Mosley

LOCATION
London Borough of Southwark

HEIGHT / STOREYS
21 ft (6.5 m) / 2 storeys

CONSTRUCTION COST
£310,000

ARCHITECT
Mosley and Mann

STRUCTURAL ENGINEER
Built Engineers / Egoin

TIMBER ENGINEER
Egoin

TIMBER CONTRACTOR
Egoin

TIMBER MANUFACTURER
Egoin

MAIN CONTRACTOR
Build-Met

TIMBER VOLUME
2,800 ft^3 (80 m^3)

TIMBER ASSEMBLY
2 days

OVERALL CONSTRUCTION
56 weeks

STRUCTURE TYPE
Pure CLT

EMBODIED CARBON WITHIN TIMBER*
-49 tons (-45 tonnes) CO_2e

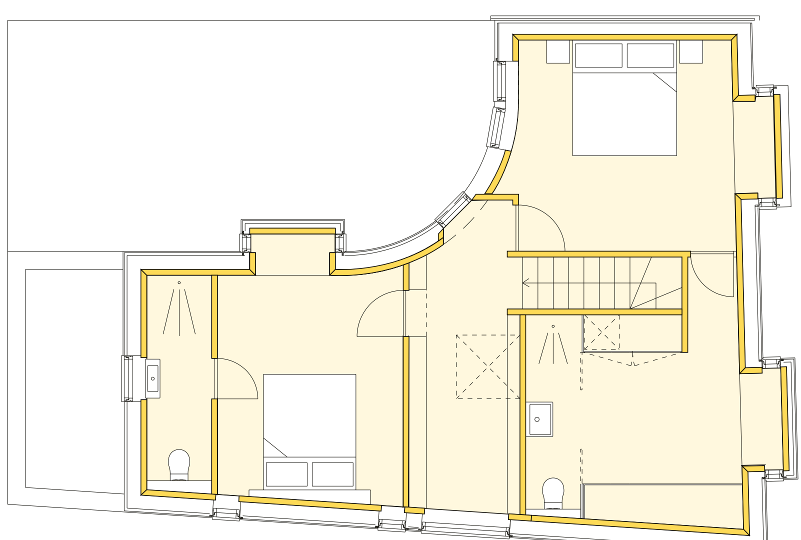
CLT FACT
CLT chosen due to access constraints

Located at the boundary of the Bermondsey Street Conservation Area, the density was key to the decision to design a "flat pack" house which could be craned and assembled in minimal time.

Prior to this project in 2006, at a time when CLT was very much in its infancy in the UK, the practice had built two award-winning solid timber buildings adjacent to the site. The panels for these two schemes were not CLT but more akin to exceptionally deep glulam beams. At the time the architects worked to overcome local resident's and building control's concerns about mass timber construction.

Permission was granted for the new project and access through the neighboring private estate agreed on the basis that a quick and quiet build time could be ensured; the success of the previous schemes acting as precedent to this.

The CLT structure of Carmarthen House took just 2 days to secure in place. All exposed internally, the timber provides a natural breathable environment with a beautiful finish. The selection of CLT for the structure enabled the interesting design features of the house to be executed easily.



First Floor Plan

© Lewis Kahn

2018

Residential (Cinema)

PITFIELD STREET

Garfwish Ltd

LOCATION
London Borough of Hackney

HEIGHT / STOREYS
61 ft (18.5 m) / 6 storeys

CONSTRUCTION COST
£9.4 million

ARCHITECT
Waugh Thistleton Architects

STRUCTURAL ENGINEER
Elliott Wood

TIMBER ENGINEER
Pryce & Myers./ KLH UK

TIMBER CONTRACTOR
KLH UK

TIMBER MANUFACTURER
KLH Massivholz

MAIN CONTRACTOR
Simply Construct

TIMBER VOLUME
18,800 ft³ (533 m³)

TIMBER ASSEMBLY
12 weeks

OVERALL CONSTRUCTION
96 weeks

STRUCTURE TYPE
Hybrid

EMBODIED CARBON WITHIN TIMBER*
-332 tons (-301 tonnes) CO_2e

CLT FACT
Using CLT allowed an extra storey due to savings in floor to floor heights

Pitfield Cinema combines the restoration of a derelict, turn of the 20th century neighborhood cinema with the development of new commercial and residential accommodation, comprising 18 luxury apartments.

The design consists of two distinct elements, a solid concrete basement and ground level, which accommodates the three-screen cinema, and a CLT element from first floor podium level to form the apartments. The timber element is stepped back from the street to provide balconies behind the historic façade. A single penthouse occupies the top floor enjoying panoramic urban views, with open plan living achieved through the use of wide spanning CLT members.

The challenge of building a cinema directly below living accommodation was achieved using 'box within-a-box' construction. The cinema is effectively isolated from the remainder of the structure. In this way, the CLT structure above is fixed onto a slab which is entirely independent of the cinema ceilings, and load paths are transferred to the foundations independently.

Constraints on the permissible height of the building were met through the use of CLT without compromising the internal room heights. The floor build-up, including underfloor heating, service voids and acoustic separation was under 16 inches thick, which is not achievable with other forms of construction.

Section

CONCLUSION

The one hundred projects featured in this book were selected from over 500 completed CLT projects in the UK. The scale and variety of buildings in CLT demonstrates that the era of engineered timber is now upon us.

We often refer to human civilisations by the principal materials they employ, such as the Bronze Age, Iron Age etc. In this vein, the 20th century can be very much called the Concrete Age and it seems very likely that the 21st century will be the Timber Age.

The adoption of engineered timber technology in construction mirrors the emergence of concrete a hundred years ago. An ancient building material, brought into modern use through enhanced engineering, the first practitioners of which chose to mimic the forms from the existing building technologies. As the use of this new material became more widespread and the capabilities became better understood, a new architecture emerged expanding the engineering possibilities concrete offered. Ultimately, a new urbanism developed, that had its impact on most cities of the world.

The hundred projects featured in this book already chart an emergence of a new architecture that owes its form to the possibilities offered by engineered timber. With the technology still in its infancy, one can only speculate as to the new forms that will emerge as the use of CLT becomes mainstream.

The tectonic expression of mass timber is still developing. New technologies demand new forms. For centuries, material innovation has been a means with which to revitalize the traditions of architecture.

As the greater use of timber in construction mirrors a changing attitude towards our planet and our living environment, the new urbanism of timber should offer us new ways of working and living together.

Image: Murray Grove, Waugh Thistleton Architects © Will Pryce

GLOSSARY

Air Tightness Line - a notional line completely enclosing a building defining the point at which airtightness measures are employed.

BIM - Building Information Modelling is a digital representation of the physical and functional characteristics of a building.

BREEAM - Building Research Establishment Environmental Assessment Method, UK certification program.

Carbon Cycle - processes such as photosynthesis, decomposition, and respiration, by which carbon, as a component of various compounds, cycles between its major reservoirs.

Carbon Reservoir / Sink - eg. the atmosphere, oceans, and living organisms which absorb and store large amounts of carbon dioxide from the earth's atmosphere.

Cascade principle - a method of increasing the efficient use of a raw material by giving priority to higher value uses that enables reuse and recycling and promotes energy use only when other options are starting to run out.

CLT - Cross Laminated Timber

CML - Council for Mortgage Lenders

CNC - Computerized Numerical Control, drilling and machining tool controlled via digital input.

Co-ordinated Drawings - a stage of building design where the structure, finishes and services are completely integrated.

Collaborative Design - the close working and partnership of all consultants and contractors in the design and construction of a building, often facilitated by BIM.

Critical path - The longest sequence of activities in a project plan which must be completed on time for the project to complete on due date.

De-lamination - for CLT, where glued layers separate, either through the action of moisture or fire.

Design Freeze - at key stages of a project the design is signed off and is fixed from that point.

Dew Point - the temperature at which water vapor in the air condenses into liquid water.

EFA - Education Funding Agency

Image: Russell Street, 5th Studio © Tim Soar

Embodied Carbon - carbon dioxide emitted during the manufacture, transport and construction of a building materials, together with end of life emissions.

Encapsulation - the approach of protecting building elements by the application of fire lining.

End grain - the grain of wood seen when it is cut across the growth rings.

Engineered Timber/Mass Timber - a generic name incorporating CLT, glulam, LVL and others.

EPD - Environmental Product Declaration

Finger Jointed - in CLT manufacture, method by which boards are joined end to end by cutting an extended sawtooth to both boards and then gluing.

Fire Integrity - the duration for which a building element or system can withstand a standard fire resistance test.

Flanking Sound - sound transmitted between spaces indirectly, going over or around, rather than directly through a floor or wall.

Follow-on-trades - refers to the activities that follow erection of a structural frame such as running services or lining out.

FSC - Forest Stewardship Council

Operational Carbon - carbon dioxide emitted during the life of a building, through heating, cooling, lighting, and power.

Glulam - Glue Laminated Timber

Heat degradation - deterioration of a material as a result of excessive heat.

Hydraulic press - more common method of CLT production, utilizing hydraulic rams for the gluing of the timber laminas.

Impact Sound - sound arising from the impact of an object on a building element, such as footsteps.

Just-in-time delivery - strategy of receiving materials on site only as they are required, reducing requirements for storage.

LCA - Life Cycle Assessment

Lead-in Period - the time required between placing an order for an item and delivery to site.

LEED - Leadership in Energy and Environmental Design, US certification system run by the U.S. Green Building Council.

Listed Building - one that is deemed of historic interest and is legally protected. Special permission from the local planning authority is required for any work to be carried out. They range from Grade II: special interest, Grade II* ("grade two star"): more than special interest and Grade I: exceptional interest.

LVL - Laminated Veneer Lumber

Mitigated Carbon - savings in carbon dioxide emissions from active measures aimed at reduction or prevention.

Moisture content - ratio of the mass of water in a material to the mass of solid.

MUF - Melamine urea formaldehyde resin is an adhesive thermosetting resin.

NHBC - National House Building Council, provides construction inspection services and 10 year warranties to UK housing developments.

NIA - net internal area.

PEFC - Program for the Endorsement of Forest Certification

Phase change material - a substance capable of storing and releasing large amounts of energy through melting and solidifying at a certain temperature.

Progressive Collapse - also known as Disproportionate Collapse, refers to when a primary structural element fails that results in the failure of adjoining structural elements, which in turn causes further structural failure.

PUR - polyurethane is type of hot melt glue that polymerizes when applied so that they form much stronger bonds than traditional hot melts.

Sequestered Carbon - the process of capture and the long-term storage of atmospheric carbon dioxide to mitigate global warming.

Service use class - a rating of 1 to 5 that identifies the recommended exposure of timber to water in use based on the characteristics of the timber itself and treatments applied.

SIPs - Structural insulated panels are a high performance building system for residential and light commercial construction.

Smoke modelling - method of simulating the behavior and temperature of smoke in the event of a fire.

Strength to weight ratio - a material's strength (force per unit area at failure) divided by its density.

Thermal Conductivity - the rate at which heat passes through a specified material, expressed as the amount of heat that flows per unit time through a unit area with a temperature gradient of one degree per unit distance.

Thermal storage capacity / Thermal Mass - the ability of a material to absorb and store heat energy. Dense materials such as brick and concrete have a high thermal mass, whereas timber has a low thermal mass.

Timber frame - traditional construction method creating framed structures from solid timber members.

UN - United Nations

Vacuum press - an alternative method of producing CLT panels by evacuating the air under a rubber based sheet.

Vapor Control Layer - a vapor tight membrane installed to a roof or wall on the inside face.

Vapor Permeable Membrane - restricts the amount of water that can pass through but does not block it, helping reduce the build-up of condensation within a structural element.

VOC - Volatile Organic Compound

54648
H1678
N4629
N0699
2L646
A4619
H1661
71607
A1669
AL665
74632
75682
40590
51619
10608
NH651
N2633
47655
71606
1H640
HN629
71583
5H710
5A634

METHODOLOGY

* EMBODIED CARBON METHODOLOGY

The embodied carbon (cradle to site) figures for each case study were calculated via the below methodology, using the sources listed. The timber volumes and delivery numbers were sourced from the architects or timber suppliers/manufacturers and the distances between the factories and sites calculated on https://www.distancecalculator.net as via road transport.

Sequestered carbon and CLT production embodied carbon:

Input = Timber Volume (m^3) = X

A = Sequestered carbon = X x -790kg CO_2 (ASBP)

B = Processing embodied carbon = X x 190kg CO_2 (ASBP)

A + B = Cradle-to-Gate embodied carbon = X x -600kg CO_2 (ASBP)

= -600X kg CO_2

Transportation of CLT:

Input = Number of Deliveries = Y

Average Distance = Zkm

Fuel Consumption = 0.44 L/km (DEFRA)

Carbon impact of fuel = 2.63kg CO_2/L (Department of the Environment, Food and Rural Affairs, 2007)

0.44Z x 2.63 = 1.157Z kg CO_2 per delivery

Y x 1.157Z kg CO_2 = 1.157YZ kg CO_2

Overall Embodied Carbon:

-600X kg CO_2 + 1.157YZ kg CO_2 = Embodied Carbon (cradle-to-site)

Image: Sawmill, Austria © Waugh Thistleton Architects

BIBLIOGRAPHY

While there is already a considerable amount of literature on cross-laminated timber, the range of references is growing constantly. A regularly updated and comprehensive list of books, press articles and technical guidance can be found at www.wt-x.net/publications.

The list below is a selection of the principal reference documents on CLT and building in mass timber.

Michael Green, **The Case for Tall Wood Buildings**, Blurb, 2018

Sylvian Gagnon and Ciprian Pirvu (ed.), **CLT handbook: cross-laminated timber**, FP Innovations and Binational Softwood Lumber Council,2011

Ireneusz Bejtka, **Cross (CLT) and diagonal (DLT) laminated timber as innovative material for beam elements**, KIT Scientific Publishing, 2011

Andy Sutton and Daniel Black, **Cross-Laminated Timber, An introduction to low-impact building materials**, BRE Press, 2011

Various, **Cross-laminated timber, Design and Performance**, Exova BM TRADA, 2017

Virginia McLeod, **Detail in Contemporary Timber Architectur**e, Laurence King Publishing, 2010

Johannes Hummel, **Displacement-based seismic design for multi-storey cross laminated timber buildings**, Kassel University Press, 2017

Simone Jeska, **Emergent Timber Technologies - Materials, Structures, Engineering Projects**, Birkhauser, 2015

Petter Bergerud, **Experimental Wooden Structures**, Bergen Academy of Art and Design, 2015

Image: Ditchling Museum of Art and Craft, Adam Richards Architects © Brotherton Lock

Jim Birkemeier, **Home Made Timer Panels - How We Make Cross Laminated Timber Panels From Our Trees at Timbergreen Farm**, Amazon, 2107

Peter Wilson, **The Modern Timber House in the UK**, Wood for Good, 2018

Robert Hairstans, **Mass Timber - an Introduction to Solid Laminate Timber Systems**, Arcamedia, 2018

Susan Jones, **Mass Timber: Design and Research**, Oro Editions, 2018

Lars Mytting, **Norwegian Wood - Chopping, Stacking and Drying Wood the Scandinavian Way**, Maclehose Press, 2015

Andrew Waugh, Karl Heinz Weiss, Matthew Wells, **A Process Revealed / Auf Dem Holzweg**, Murray & Sorrell FUEL, 2009

Joseph Mayo, **Solid Wood: Case Studies in Mass Timber Architecture, Technology and Design**, Routledge ,2015

Jack Porteous and Andy Kermani, **Structural Timber Design to Eurocode 5**, Wiley-Blackwell, 2nd Edition, 2013

James Norman, **Structural timber elements, a pre-scheme guide**, Exova BM TRADA, 2016

Andrew Bernheimer (ed.), **Timber in the City: Design and Construction in Mass Timber**, Oro Editions ,2015

Michael Dickson, **Sustainable Timber Design**, Routledge ,2015

Josef Kolb, **Systems in Timber Engineering**, Birkhäuser, 2018

Michael Green, Jim Taggart, **Tall Wood Buildings - Design Construction and Performance**, Birkhäuser, 2017

Ulrich Daniel, **Turning Point in Timber Construction - A New Economy**, Birkhäuser, 2016

United Nations, **World Urbanization Prospects**, The 2014 Revision, Highlights (New York, United Nations, 2014)

Over the last 15 years the UK has experienced a quiet revolution in construction. Since the modest efforts of the first small buildings in the early 2000s a blossoming array of CLT projects has emerged across a range of building types and scales. In 2017, three out of the five buildings nominated for the Stirling Prize, the UK's top architecture award, were constructed from CLT. Engineered timber buildings are now firmly part of our construction landscape.

This book presents the case for using engineered timber with one hundered studies encompassing a wide range of scales, styles and types.

Also included is a compendium outlining the benefits of CLT along with the considerations for designing and building in this revolutionary material.