How to Build a Low-Carbon Home

Large Print Guide

the DESIGN MUSEUM

INTRODUCTION

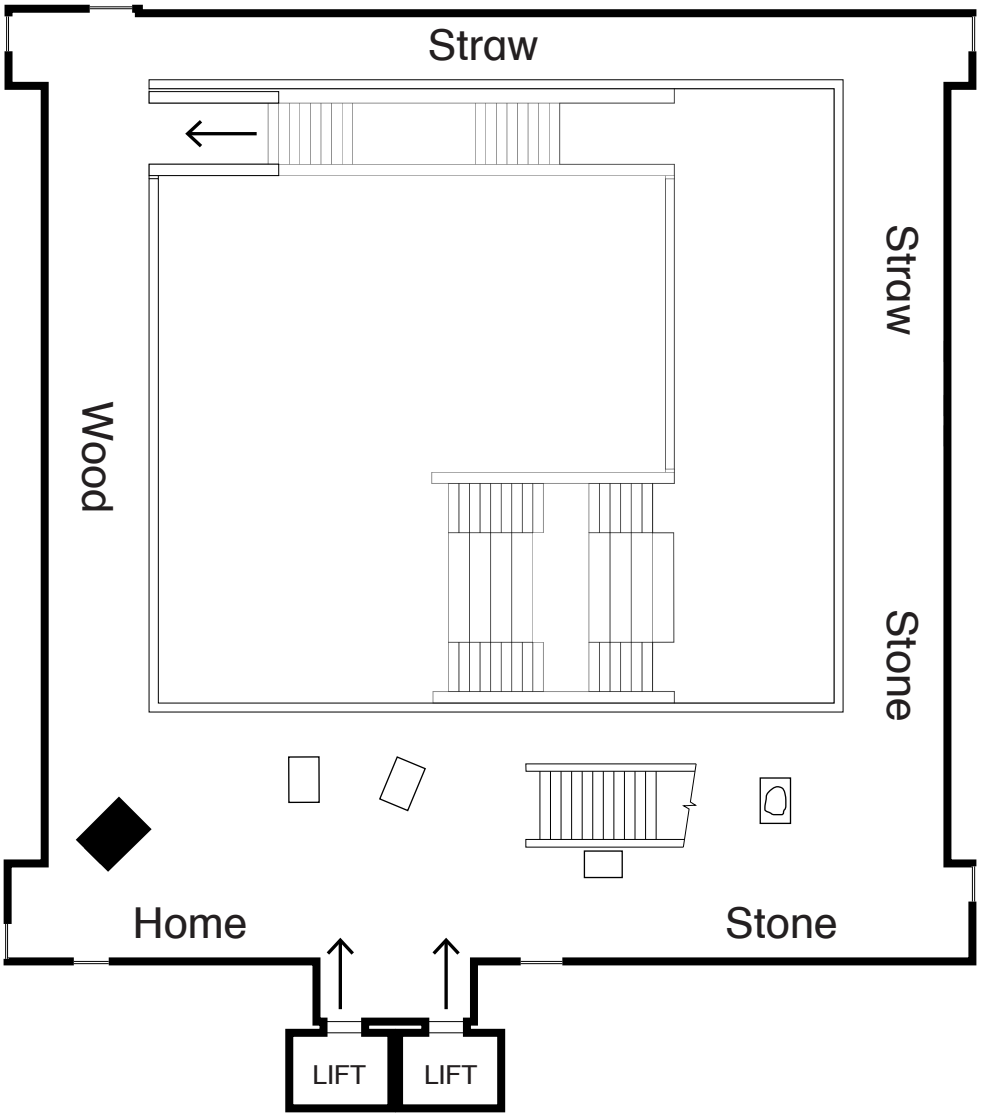
Responding to the climate emergency will mean changing many aspects of our lives, including the way we design our homes.

Together, the construction and running of buildings is one of the largest causes of global carbon emissions. The materials typically used for construction, such as steel and concrete, are carbon-intensive to produce, and buildings require energy to operate.

How will we design homes for a low-carbon future? And how are architects repurposing familiar materials for the homes of tomorrow?

This display tells the story of three building materials that we might not associate with the future: stone, wood and straw. While they may sound old-fashioned, these traditional materials are being used in new and innovative ways to design homes fit for the 21st century.

Through the work of architects Material Cultures, Waugh Thistleton and Groupwork, follow the journey of these materials from fields, forests and quarries to cutting-edge buildings that reimagine the housing of tomorrow.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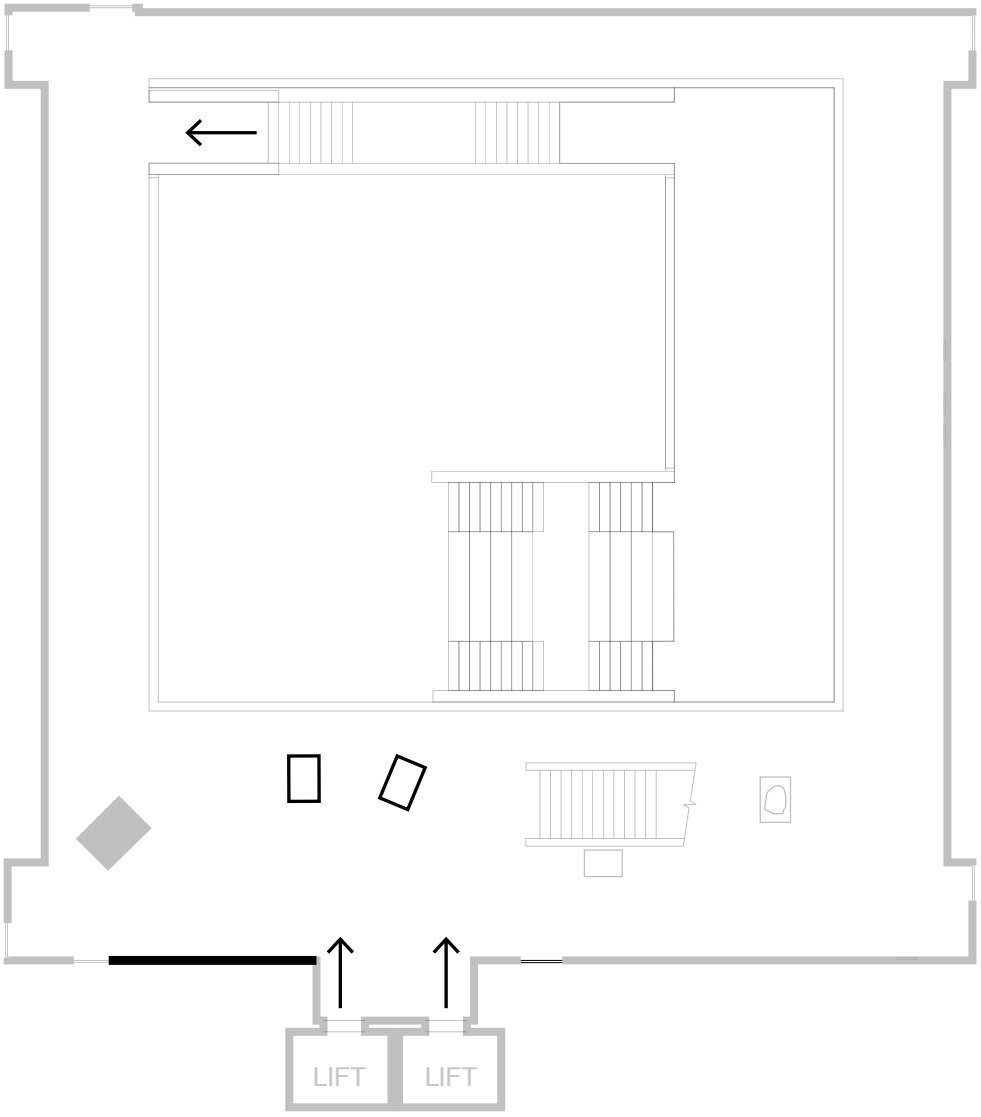


Embodied carbon

The United Nations Environment Programme reports that buildings and construction represent 37% of global CO_2 emissions, divided between ‘operational’ and ‘embodied’ carbon. Operational carbon is the emissions generated by a building in use (for example, in heating). Embodied carbon is the focus of this display, and describes emissions associated with producing materials used for construction. This accounts for around 9% of global CO_2 emissions, and steel, concrete and cement are major contributors. The building and construction sectors will need to reduce their carbon footprint by working with alternative materials.

Embodied carbon means all the carbon dioxide emitted in producing a material. This includes all emissions that arise from extracting, transporting, manufacturing and installing building materials on site. The lower the embodied carbon of a material, the better it is for the environment.

Bringing Embodied Carbon Upfront
World Green Building Council
2019
Duration: 2 minutes, 19 seconds
Courtesy of World Green Building Council

This model shows the different layers of a cross-laminated timber (CLT) building. The wood holds the building up behind additional materials for soundproofing, flooring, decoration and weatherproofing.

Model of Murray Grove
Waugh Thistleton Architects
2009
CLT, fibre cement, plywood, MDF, plasterboard, plastic pipe, metal bracket
Courtesy of Waugh Thistleton Architects

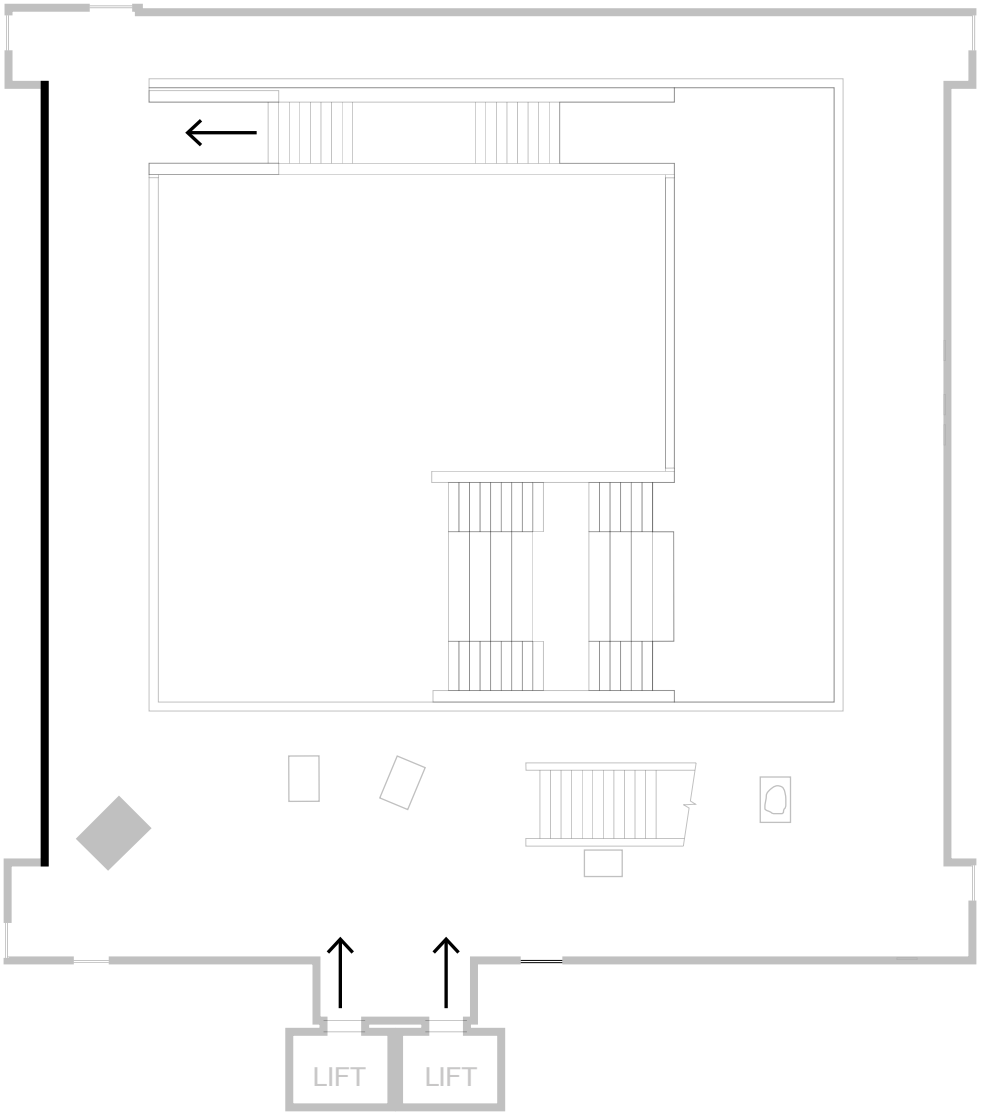
This fragment of a low-carbon house was made by students at Central Saint Martins. Guided by architects Material Cultures, their design features a thatched roof, clay tiles and load-bearing walls made from timber and straw. The clay tiles ensure waterproofing outside, and acoustic and thermal insulation inside.

The Long Straw — Wheat
Produced by students from the M ARCH: Architecture course at Central Saint Martins College of Art and Design, taught by Material Cultures (Paloma Gormley, Summer Islam, Daria Moatazed-Keivani and Will Bradley) as part of the Spatial Practices' Forest School programme.
2023
Straw, clay, timber
Courtesy of M ARCH: Architecture, Central Saint Martins
Courtesy of Knoll

Clay bricks, concrete and steel are some of the most widely used building materials in the UK. However, they are high in embodied carbon – a large amount of energy is required to make them. In contrast, stone, timber and straw-based materials have significantly lower embodied carbon and are far less environmentally damaging.

Home

Wood



Timber – wood used for construction or carpentry – is an ancient and low-carbon building material. Timber for construction fell out of favour for much of the 20th century, as large and complex structures required stronger materials. But in recent decades the development of mass timber, also known as engineered timber, has provided an exciting alternative to concrete and steel construction.

By gluing, nailing and otherwise processing wood pieces into composites, engineered timber elements are being developed to create astonishing new buildings, including the first timber high-rises.

As trees grow, they absorb carbon dioxide from the atmosphere through a process called photosynthesis. Their leaves pull in carbon dioxide and water, and use the energy of the sun to convert this into chemical compounds such as sugars that feed the tree. The carbon is stored in the tree until it rots or is burnt.

Dodd Wood, Northwest England Forest District
Photography by Isobel Cameron
2006

Courtesy of Forestry Commission

Should we be cutting down trees to make buildings?

As trees grow they absorb CO_2, but this stops when they mature. As they die and rot, the CO_2 they stored during their lifetime is released back into the atmosphere and contributes to global heating. By cutting down trees responsibly, using timber to build houses and replanting forests, we can maintain a balanced carbon cycle, ensuring that the CO_2 is kept in the materials we use to build our homes.

Coniferous trees like spruce, pine and larch are used most often to produce engineered timber. These softwood trees grow much more quickly than hardwoods such as beech or oak.

The Architecture of Trees
Cesare Leonardi and Franca Stagi
1983
Courtesy of the Design Museum

Working with wood

Timber can be processed to make different building materials. For engineered timber, wood from trees is cut into boards, stacked in layers and then joined together using glue, dowels and other methods. The stacked layers can be used to produce structural building components, including beams, columns and wall panels.

Making cross-laminated timber from American tulipwood
Film by Petr Krejčí
MultiPly was designed by Waugh Thistleton Architects and engineered by Arup for the London Design Festival in 2018. It was made using engineered cross-laminated American tulipwood to form pre-fabricated dismountable boxes.
2018
Duration: 1 minute, 40 seconds
Courtesy of the American Hardwood Export Council

Cross-laminated timber (CLT) sample
Spruce
Courtesy of Waugh Thistleton Architects

Dowel-laminated timber (DLT) sample
Spruce
Courtesy of iQwood

Glue-laminated timber (GLT) sample
Douglas fir
Courtesy of Waugh Thistleton Architects

Researchers across the UK are working to make construction faster, safer and less wasteful. This CLT joint was cut by a robot as part of research at Robert Gordon University, Aberdeen, in collaboration with Glulam Solutions, a timber engineering company. Design research often involves different stages of trial and error – look closely at the joint and you will notice the mistakes made by the robotic arm.

Robot arm cutting CLT joints
Robert Gordon University in collaboration with Glulam Solutions, funded by BE-ST
2022
Duration: 2 minutes, 35 seconds
Courtesy of Roubo

CLT joint
Robert Gordon University in collaboration with Glulam Solutions, funded by BE-ST
2022
Plywood CLT
Courtesy of Roubo

Building with wood

Waugh Thistleton Architects are timber specialists and have championed its use since their first CLT (cross-laminated timber) building in 2003. Their projects include Murray Grove, a nine-storey tower in London that was the first tall urban building made from prefabricated timber. Their Dalston Works scheme contains 121 flats in what was the world's largest CLT building upon its completion in 2017.

Building with engineered timber is fast. The structure of Murray Grove, a nine-storey building designed by Waugh Thistleton Architects, was completed in just 27 days. This means fewer polluting emissions and less disruption for people who live and work nearby.

Curtain Place, Shoreditch, London
Waugh Thistleton Architects
2015
Duration: 50 seconds
Courtesy of Waugh Thistleton Architects

Hurst Avenue, Highgate, London
Waugh Thistleton Architects
2015
Duration: 30 seconds
Courtesy of Waugh Thistleton Architects

Dalston Works, Hackney, London
Waugh Thistleton Architects
2015
Duration: 1 minute, 26 seconds
Courtesy of Waugh Thistleton Architects

Woodberry Down, Finsbury Park, London
Waugh Thistleton
2015
Duration: 43 seconds
Courtesy of Waugh Thistleton Architects

Thanks to prefabrication and lighter-weight materials, engineered timber builds are often quieter, cleaner and quicker than regular builds. Parts can be prefabricated in a factory, before being transported to site and quickly assembled using drills and screwdrivers.

Model lorry with prefabricated structure
Plastic, wood
Courtesy of Waugh Thistleton Architects

Is wood a fire risk?

Following the tragic fire at the Grenfell Tower in 2017, people are rightly concerned about building materials and fire safety. The UK government brought in a ban on combustible exterior materials, including engineered timber, in 2018. However, advocates of engineered timber argue that it can be safer than steel in a fire. It remains structurally stable for longer and does not produce toxic fumes when it burns.

This is one of the largest CLT buildings in the world. Waugh Thistleton designed Dalston Works to address the need for low-carbon homes in London. It is a ten-storey building containing 121 homes but weighs a fifth of an equivalent concrete building.

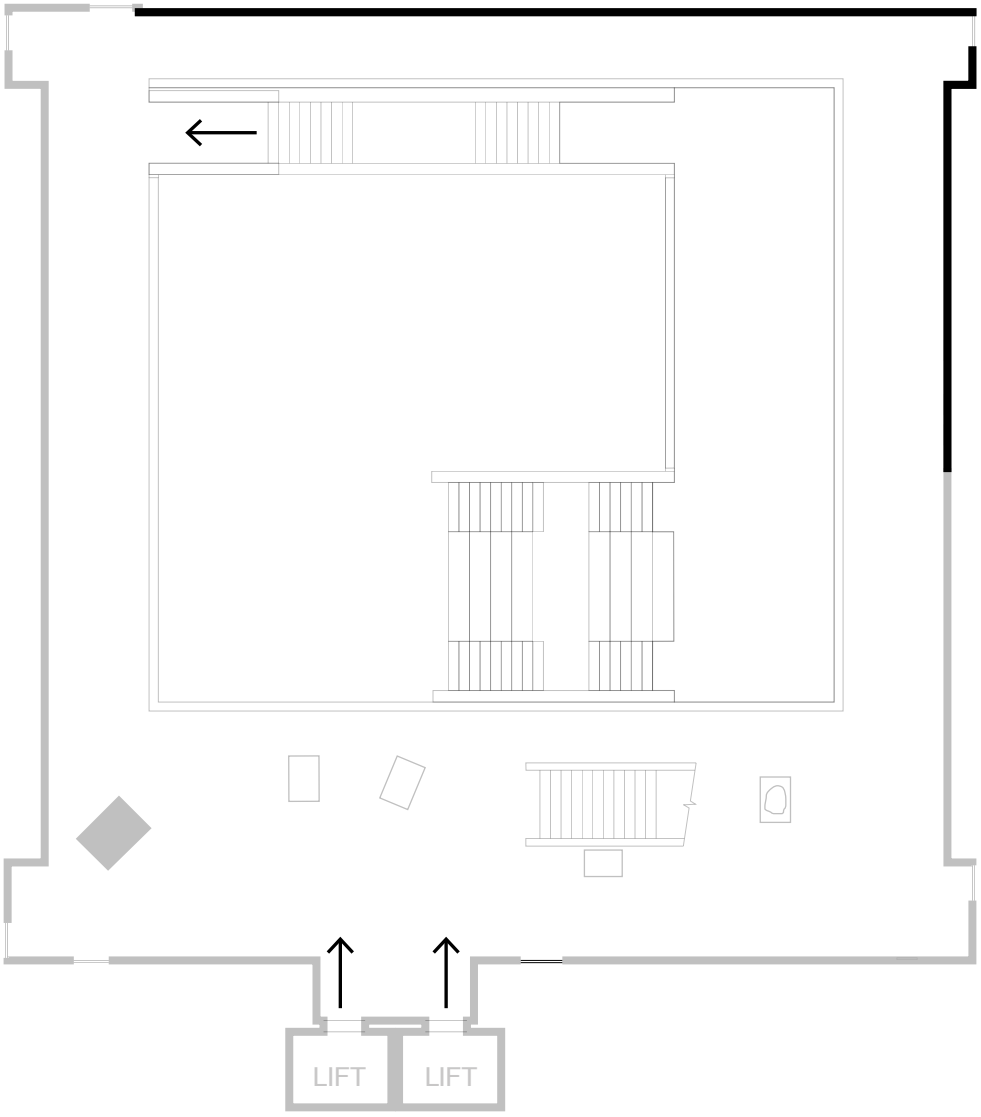
Model of Dalston Works, Dalston, London
Waugh Thistleton Architects
2017
Plywood
Courtesy of Waugh Thistleton Architects

Construction of Dalston Works, Dalston, London
Photography by Daniel Shearing
2017
Courtesy of Waugh Thistleton Architects

Interior of Rye Apartments, London
Photography by Oskar Proctor
Architecture by Tikari Works
2023
Courtesy of Oskar Proctor

CLT Beam
2023
Courtesy of Ecosystems Technologies

Straw



Although it may seem like a flimsy by-product of farming, straw has an amazingly diverse range of uses in construction.

Straw is a catch-all term for the stalks of cereal plants – such as flax, hemp, barley, rice, wheat, rye and oat – that are left over when the grain has been removed.

Straw can be used for building in many different ways, by combining it with other natural materials such as clay or bio-waste resins to make walls, bricks, insulation and other modern components. Straw also absorbs carbon dioxide when it grows, making it an environmentally friendly material for contemporary homes.

Straw can be gathered in bales to be used as structural elements or insulation. It can be mixed with other materials to make earth bricks or walls, or bunched to make thatch,
a weatherproof material for roofs and facades.

Field of wheat
Photography by Kirill Gorlov
Courtesy of Adobe Stock

Straw is used in earth bricks and other natural building blocks as a binding material. Natural building blocks are usually air dried, meaning they require much less energy to produce than regular construction bricks, which have to be fired in a kiln at very high temperatures.

Hempcrete brick
Material Cultures
2022
Hemp, lime
Courtesy of Material Cultures

Strock (earth) brick
Material Cultures
2022
Clay, earth, straw
Courtesy of Material Cultures

Chalk/straw brick
Local Works Studio
2021-2023
Waste chalk, straw
Courtesy of Local Works Studio

Block mould used to form bricks
Unfired clay brick, wood
Courtesy of Local Works Studio

These blocks were made by Local Works Studio, a design practice who create low-carbon building materials. The blocks can be used for insulation and are made from agricultural by-products sourced locally in East Sussex.

Plant/lime blocks and bricks
Local Works Studio
2021-2023
Agricultural by-product plant material, lime
Courtesy of Local Works Studio

Would my straw house fall down or catch fire?

Don’t worry about the Three Little Pigs and the Big Bad Wolf – materials for buildings made with straw are safe to use. Thatch can be fire-resistant in the same way as concrete or bricks if carefully constructed and finished with a plaster-like mix called render. Rammed-earth bricks, hemp and other straw-based materials are strong enough to build houses that nobody could blow down.

Venice test bricks
Designed by Local Works Studio
Architects Urban Radicals
Engineers AKTII
Project funded by Tyréns
2021-2023
Canal silt, waste aggregates, lime, hemp fibre
Courtesy of Local Works Studio

Straw
Film produced by Material Cultures and edited by Ella Frost
2023
Duration: 6 minutes, 40 seconds
Courtesy of Material Cultures

Working with straw

Can you imagine your home with a thatched roof? Straw has been used to thatch roofs since the Bronze Age, over 4,000 years ago, and can still be an effective material to keep buildings warm and protected from the elements. As well as roofs, thatch can be used for a building's facade – its outside walls – to create a well-insulated and weatherproof skin.

Thatching is a complex process requiring specialist skills and tools. Bundles of straw are pinned to a roof with a spar, similar to a staple, and hit with a leggett to create an even surface. Steel wires hold the straw to the roof, screwed into place with a specialist screwdriver called a twister.

Tools used for thatching

Spar used for thatching
Courtesy of Shelley Master Thatcher

Mallet used for thatching
Courtesy of Shelley Master Thatcher

Forged and welded pins used for thatching
Courtesy of Shelley Master Thatcher

Twister used for thatching
Courtesy of the Design Museum

Leggett used for thatching
Courtesy of Shelley Master Thatcher

Shears used for thatching
Courtesy of Shelley Master Thatcher

Thatch facade on Sundby School in Guldborgsund Kommune, Nykøbing Falster, Denmark
Joint architecture project by Henning Larsen and Skala Architecture
Photography by Rasmus Hjortshøj
2023
Courtesy of Henning Larsen and Rasmus Hjortshøj

Building with straw

Straw-based materials are often associated with traditional buildings, but a new generation of architects is revolutionising these materials for exciting contemporary homes. Material Cultures is an architecture practice and material research lab exploring design possibilities for a post-carbon built environment. Their buildings and research are pioneering the use of straw-based construction and other regenerative design techniques for contemporary homes, such as Flat House in Cambridgeshire.

Flat House is a three-bedroom home at Margent Farm, Cambridgeshire, built using natural materials including hemp fibre cladding and hempcrete. The hemp used for the building was grown on the farm itself, and the house's main structure was built in just two days.

Constructing Flat House, Margent Farm, Cambridgeshire
Photography by Material Cultures
2020
Courtesy of Material Cultures

Drawing of Flat House, Margent Farm, Cambridgeshire
Material Cultures
2020
Courtesy of Material Cultures

Prefabricated timber frames (known as cassettes) can be used to create panels for quickly building low-carbon houses. This cassette is filled with hempcrete – a mixture of hemp, lime and water – for insulated walls.

Installing a prefabricated hemp panel at Flat House, Margent Farm, Cambridgeshire
Photography by Material Cultures
2020
Courtesy of Material Cultures

Exterior of Flat House, Margent Farm, Cambridgeshire
Photography by Oskar Proctor
2020
Courtesy of Oskar Proctor

Hemp fibre can be used to clad buildings by mixing hemp straw with a bio-waste resin. Hemp crops can absorb 15 tonnes of carbon dioxide per hectare – a huge amount – making hemp much more environmentally friendly than other cladding materials such as steel or plastic.

Hemp fibre cladding
Material Cultures
Hemp, bio-resin
Courtesy of Material Cultures

Is hemp illegal?

While hemp and marijuana come from the same plant species, hemp products only have very small amounts of THC, the psychoactive chemical in marijuana. It is legal to grow industrial hemp in the UK with the correct licence. However, farmers can only cultivate the stems and seeds of hemp. The leaves and flowers fall under the category of marijuana and so are a controlled substance.

This fragment of a low-carbon house was made by students at Central Saint Martins. Guided by architects Material Cultures they were tasked with investigating how thatching techniques can be modernised. The students created a modular system of thatching with reed, so that they could create prefabricated panels suitable for housebuilding on a national scale.

The Long Straw — Reed

Produced by students from the M ARCH: Architecture course at Central Saint Martins College of Art and Design, taught by Material Cultures (Paloma Gormley, Summer Islam, Daria Moatazed-Keivani and Will Bradley) as part of the Spatial Practices' Forest School programme.

2023

Straw, clay, timber

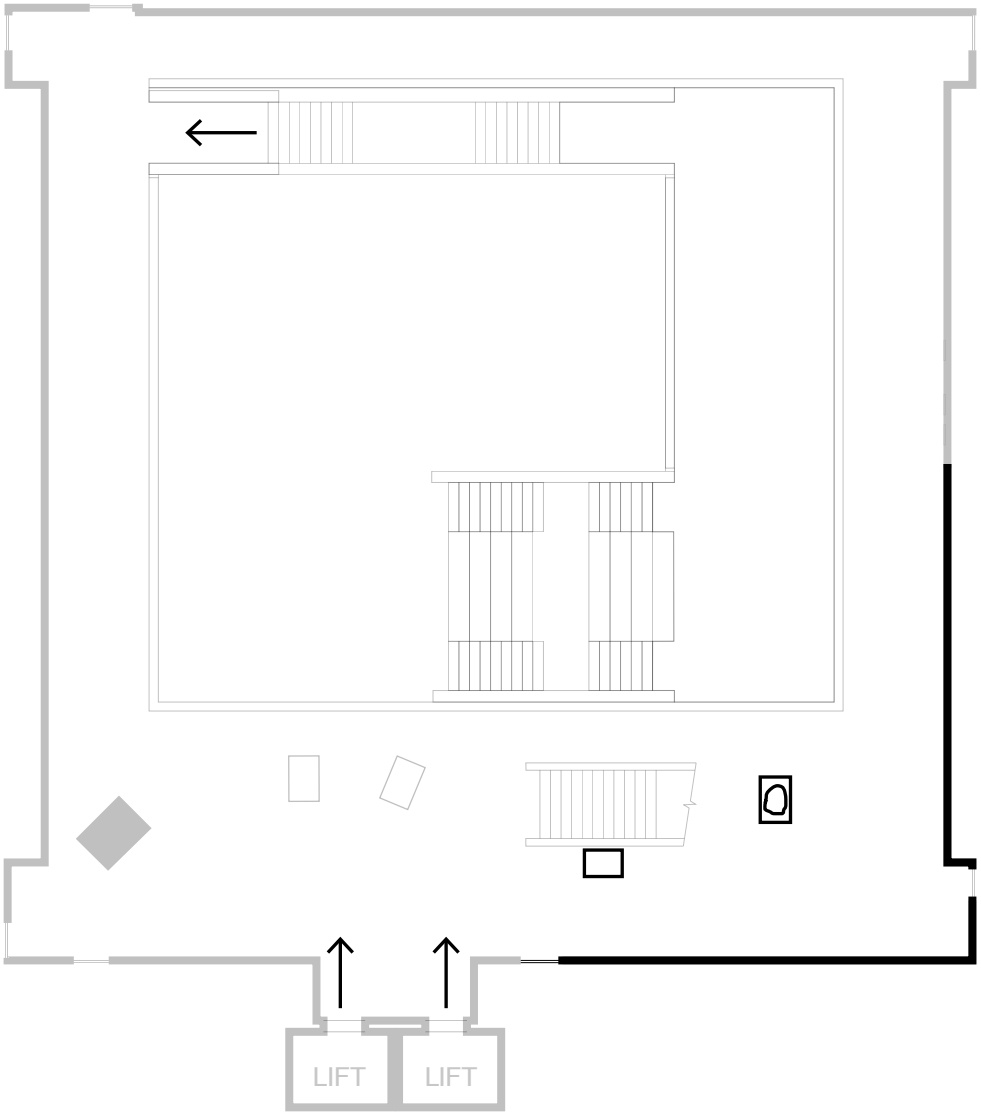
Courtesy of M ARCH: Architecture, Central Saint Martins

Straw-based construction materials are starting to be used for larger housing developments. The Phoenix is a planned sustainable neighbourhood that will provide 700 new homes in Lewes, East Sussex. Material Cultures have designed houses for this new neighbourhood that will use prefabricated timber cassettes filled with a hemp and lime mixture for insulation.

Rendering of Phoenix housing project
Material Cultures
2023
Courtesy of Material Cultures

Interior of Flat House, Margent Farm, Cambridgeshire
Photography by Oskar Proctor
Architecture by Material Cultures
2023
Courtesy of Oskar Proctor

Stone



Stone has been used for generations as a robust and versatile material for building homes and towns across the UK, including the historic centres of Edinburgh and Bath. Despite this legacy, the use of stone for construction dwindled following the advent of reinforced concrete and steel in the 19th century. Today it is largely used for decorative purposes.

Yet unlike concrete and steel, stone is an abundant resource found in the earth's crust. It can be three times stronger than concrete and requires much less energy to produce. Can stone be revived to build 21st century homes?

Stone comes in a wide array of colours, textures and properties, which provide many possibilities for construction. We can trace the type of stone in each area by the distinctive look of the regional architecture.

Bedrock Geology of the UK & Ireland (scale 1:1,250,000)
British Geological Survey
2017

Lazonby stone sample

St Bees stone sample

Guiting Gold stone sample

Ancaster stone sample

Clipsham stone sample

Portland Heritage stone sample

Portland stone sample

Courtesy of The Stonemasonry Company

Working with stone

Stone is extracted from the earth's crust in quarries, after which it is split and cut to make building components such as columns or blocks. The Stonemasonry Company in Lincolnshire is one of the key advocates for the use of structural stone in the UK. Their stone masons use specialist tools to make precisely carved parts. Building with stone is energy efficient because the material requires very little treatment after it has been quarried.

The UK has a long history of building with stone. St Paul's Cathedral is one of the most famous landmarks in London and was predominately built from Portland stone quarried in Dorset.

St Paul's Cathedral, London: south elevation of the Great Model

Graphic reproduction
Sir Christopher Wren
Printed 2023. Created c. 1725
Courtesy of Royal Academy of Arts, London

Model of St Paul's Cathedral

Shape Print
2023
3D-printed model
Courtesy of the Design Museum

This quarry supplied most of the distinctive sandstone for Edinburgh's New Town. The quarry is surprisingly small to provide material for so many buildings, and today is covered by a car park.

Craigleith Quarry, Edinburgh
Photography by William Donaldson Clark
1860
Courtesy of HES (Historic Environment Scotland)

At first glance, quarries may seem intrusive, but they are spatially efficient and, when no longer needed, can be reused for leisure and education purposes, or rewilded.

Luget Quarry, Charente, France
Photography by Pierre Bidaud
2022
Courtesy of The Stonemasonry Company

Cutting stone at Massangis quarry, Burgundy, France
Film by Amin Taha
2019
Duration: 27 seconds
Courtesy of Amin Taha

If we build more with stone, will there be quarries everywhere?

There are concerns that too many quarries might damage the landscapes we are trying to protect. However, the structural capabilities of raw stone make quarries highly efficient in comparison to the mines and polluting industrial facilities required for the production of concrete or steel. What's more, quarries can easily be rewilded or repurposed when they are no longer in use: the Centre for Alternative Technology, an ecological school in Wales, is on the site of a disused slate quarry.

The Stonemasonry Company: The Stone Yard
Film by The Stonemasonry Company
Directed by Joseph Bushell
2022
Duration: 48 seconds
Courtesy of The Stonemasonry Company

Diamonds are among the strongest materials on earth. Even in tiny quantities, they can cut through hard materials. This wire is embedded with diamond beads and was used to cut stone by running at very high speeds.

Piece of diamond wire
Diamond and stainless steel
Courtesy of The Stonemasonry Company

The tools used to lift and split stone have not changed for generations. By drilling a single hole into a block of stone, you can split it by inserting two ‘feathers’ and a plug, which is hit with a hammer. A lewis pin is used to lift stone. Its two pins grip the stone like two fingers.

Craigleith Quarry, Edinburgh
Steel
Courtesy of The Stonemasonry Company

Lewis pin
Steel
Courtesy of The Stonemasonry Company

Clay bricks are one of the most widely used building materials. However, they require a lot of heat and energy to produce. These bricks are made from stone instead of clay. They do not require firing, they are stronger than clay bricks and they have significantly less embodied carbon.

Bricks courtesy of Albion Stone, Hutton Stone and Lime Green Products
Constructed by Lee Marley Brickwork and Construction Youth Trust
Howley Park, St Bees, Locharbriggs, Doddington, Darney, Portland stone and lime mortar

Many stone elements are still cut and carved by hand. At The Stonemasonry Company in Lincolnshire, each stone mason has their own booth where they carry out their work, as well as their own set of tools. They work from templates and engrave each finished piece with their own symbol: their mason's mark.

Set of tools used for carving stone
Steel
Courtesy of The Stonemasonry Company

Stone carving booth at The Stonemasonry Company
Photography by The Stonemasonry Company
2022
Courtesy of The Stonemasonry Company

Set of templates for a step
Plastic
Courtesy of The Stonemasonry Company

Section of stone staircase
The Stonemasonry Company
2023
Portland stone
Courtesy of The Stonemasonry Company

Is stone expensive?

As stone has been used mostly in decorative ways over recent decades, there is a perception that it is only an expensive or luxurious material, best used for high-end interior design. However, there are different types of stone and many are familiar materials for everyday uses, including the paving outside the Design Museum.

Building with stone

Groupwork is a London-based architecture practice which, along with engineers Webb Yates, has been pioneering the use of structural stone for robust, stylish and low-carbon contemporary buildings. Groupwork and Webb Yates collaborated on 15 Clerkenwell Close, a five-storey office and residential building in central London. This was nominated for the 2021 Stirling Prize, the UK's most prestigious architectural award.

15 Clerkenwell Close's limestone facade acts as a self-supporting exoskeleton, which holds up the building and the floor plates inside. It is a low-carbon alternative to a typical steel frame.

Model of 15 Clerkenwell Close, London
Groupwork
2017
Perspex, limestone, cement
Courtesy of Groupwork

Groupwork's 15 Clerkenwell Close is a residential and office building that brings stone to the forefront. The project's key feature is its exoskeleton of raw quarried limestone, which acts as both structure and facade.

Footage of 15 Clerkenwell Close by Groupwork as part of the RIBA Stirling Prize 2021 film series
RIBA Architecture
2021
Duration: 2 minutes, 39 seconds
Courtesy of The Royal Institute of British Architects

Interior of 15 Clerkenwell Close, London
Photography by Oskar Proctor
Architecture by Groupwork
2023
Courtesy of Oskar Proctor

What next...?

This display looks at building with stone, timber and straw separately, but these materials can also be used together. For example, stone works well as a structural material, timber makes great beams for support and straw is an effective material for insulation and roofs.
In order to transform the construction industry for a low-carbon future, we will need to increase the local supply of these materials and train a new generation of skilled construction workers to build with them.

Imaginary low-carbon house
Webb Yates Engineers
2023
Douglas fir, travertine marble, grass
Courtesy of Webb Yates Engineers

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This display is part of Low-Carbon Housing, a Future Observatory research project driving sustainable housebuilding in the UK. Future Observatory is the Design Museum's national research programme for the green transition. It is coordinated by the museum in partnership with the Arts and Humanities Research Council (AHRC), which is part of UK Research and Innovation (UKRI).

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The Design Museum is committed to reducing the environmental impact of exhibitions and displays. For this project, the team has re-used exhibition furniture, reduced the transport distance of objects on view and worked closely with contractors to find the most sustainable materials and production processes possible.

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For more information on the Design Museum's approach, and to download a guide to reducing the environmental impact of exhibitions, follow the QR code.

Images

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