Melbourne School of Design

Faculty of Architecture, Building and Planning

The University of Melbourne

Building 4.0 Cooperative Research Centre

CIRCLE

Australian Government
Department of Industry, Science and Resources

Cooperative Research Centres Program

Project Circle Phase 1.0
December 2025

About

This report describes *#108 Project Circle Design Phase 1,* a six month research project running from June 2025, funded and supported by Building 4.0 Cooperative Research Centre.

Project conducted by:

Professor Dan Hill, Director of Melbourne School of Design, Faculty of Architecture, Building and Planning, The University of Melbourne

André Bonnice, Architect, Simulaa, and Education Fellow at Melbourne School of Design, Faculty of Architecture, Building and Planning, The University of Melbourne

Dr. Christopher Jensen, Lecturer in Construction Management, Faculty of Architecture, Building and Planning, The University of Melbourne

Project partner:
Lendlease Development

Further information:
https://building4pointzero.org/projects/108-project-circle-design-phase-1/

How to cite this document:
Hill, D, Bonnice, A, & Jensen, C (2026) *'Project Circle Phase 1'*. The University of Melbourne

Melbourne School of Design
Faculty of Architecture, Building and Planning
The University of Melbourne

We acknowledge the Traditional Owners of the unceded land on which we work, learn and live. We recognise the unique place held by Aboriginal and Torres Strait Islander peoples as the original owners and custodians of the lands and waterways across the Australian continent, with histories of continuous connection dating back more than 60,000 years. We also acknowledge their enduring cultural practices of caring for Country, and recognise the deep and meaningful relationships with the subject of this work: the manifold flows, temporalities, textures, cultures, and systems of natural materials embedded and embodied in Country.

We pay respect to Elders past, present and future. As a community of practitioners in the built and living environment, as well as researchers and teachers, we are privileged to work and learn every day with Indigenous colleagues and partners.

We will continue working to move beyond acknowledgment and towards reciprocal relationships with the Traditional Owners and First Nations people of this land.

Contents

Summary

The built environment sector is the most significant driver of climate change, resource depletion, and biodiversity loss. It must be fundamentally transformed if it is to work within planetary boundaries. Project Circle follows the Australian Reduction Roadmap in sketching out aspects of this systemic transformation.

Whilst roadmaps outline the emissions budgets that construction must work within, Circle responds by foregrounding the sector's *materiality* as the challenge, and the opportunity. It offers a lens through which we might glimpse a built environment sector that works within planetary boundaries. Current sustainability practices focus on operational energy in buildings, but embodied emissions—arising from materials, and their extraction, processing, manufacturing, transport, construction, and demolition—represent a growing share of total impact. Further, an emphasis on 'carbon counting' has failed to capture broader ecological degradation embedded in material supply chains. The impact of material choices have largely been ignored by the mainstream built environment sector.

The first phase of Circle introduces a framework for understanding materials, as a generative 'rule-of-thumb' to support better decision-making, making clear the creative potential in holistic material choices for a regenerative construction sector working within planetary boundaries.

Materials are assessed across six criteria, structured as two interacting sets. 'Planet-aligned' criteria indicate those that have positive impact across circularity, low emissions, and ecosystems. The second set of 'industry-aligned' criteria recognise typical cost-oriented aspects: the ability to produce at scale and with speed, and with durability minimising maintenance costs. Plotting these aspects on a simple visualisation allows for a multi-criteria evaluation, deliberately balancing planetary boundaries with industrial realities.

The framework is applied to ten commonly used construction materials, and their use in typical building elements. A 'planet-aligned' set—hemp, straw, timber, stone, earth—performs strongly in terms of circularity, embodied emissions, and ecosystem impact, particularly when locally sourced and responsibly managed. Industry-aligned materials—concrete, steel, glass, brick, plaster—dominate the mainstream construction sector, largely due to established infrastructures and regulatory frameworks producing speed and scale, and a preference for durability over regeneration. Yet they carry very high embodied emissions and have disastrous impacts on ecologies.

Circle's analysis immediately reveals that productivity, efficiency and scale can no longer be seen as ends in themselves. Given its impact, the direction of the sector must be rapidly reoriented towards regenerative circularity, low emissions, and ecological repair and retrofit. The industry-aligned criteria must become planet-aligned.

Circle suggests a rich and diverse palette of viable regenerative materials for the sector, and explores how they might be deployed across numerous examples of inventive and progressive architecture and construction. It also emphasises that material choices are shaped by the *'dark matter'* of regulation, policy, finance, and institutional norms. Without reform of these systemic drivers, as well as design and building practices, the industry is unlikely to transform at the necessary pace. Circle outlines how public sector innovation can create markets and reorient sectors toward lower-impact materials.

The project concludes with sketches of prototypes, each demonstrating how circular materials might underpin viable building systems. Ultimately, Circle reframes construction, seeing designing and building as embedded in material flows, producing local and global resilience from within a non-extractive architecture.

Circle's first phase includes a critical discussion of the criteria and the practices it implies. It outlines an initial material analysis and indicates how prototypes can expand and enrich public perceptions whilst cultivating new material practices across industry, government, education, and community. Future phases aim to further refine the criteria, include novel materials, and help develop innovative policy and regulatory pathways and settings. Circle indicates how Australian construction might be aligned within planetary boundaries to produce a thriving, materially regenerative built environment.

> Modern man does not experience himself as a part of Nature but as an outside force destined to dominate and conquer it. He even talks of a battle with Nature, forgetting that, if he won the battle, he would find himself on the losing side.

E.F. Schumacher
Small Is Beautiful (1973)

Circle / Part 1 / Introduction

Rationale Method Criteria Portfolio

Hyllie building, Malmö Kaminsky Arkitektur (2026)

This mixed-tenure housing could be considered the world's largest straw building. Designed by Kaminsky Arkitektur, it features EcoCocon's wall system straw panels, with a glulam timber core and timber cladding. Pictured during construction, December 2025.

What's the problem?

> Whenever we build, we either contribute to or counteract dominant processes of change. It is increasingly clear that the industrialised ways of making buildings with concrete, steel, and petrochemicals that came to dominate construction in the twentieth century are changing the world in ways that are profoundly damaging, not only at the site of construction but across a vast network of sites of material extraction, processing, transportation and warehousing.
> Material Cultures (2020)

The construction industry is one of the most significant drivers of climate change, resource depletion, and biodiversity loss. Globally, buildings and infrastructure account for nearly 40 per cent of greenhouse gas emissions and the largest share of raw material extraction (UNEP 2022). Without transformation, the construction sector's greenhouse gas emissions footprint will singlehandedly exceed the per-annum carbon budget for the 1.5 °C and 2 °C goals in the next two decades, and use up the remaining carbon budget for the 1.5 °C goal by 2050 (Li et al 2025). The World Economic Forum finds that biodiversity loss and ecosystem collapse is the second most severe long term risk facing humanity, after extreme weather events (WEF 2026). Both of these risks might be linked to construction, through ecosystem impact and emissions. Construction is typically the largest generator of waste (DCCEEW 2025). The Planetary Boundaries framework developed by the Stockholm Resilience Centre shows that six of nine planetary systems, including climate change, biodiversity, land-use, and biogeochemical flows, have already been exceeded (PBScience 2025).

Staying within these limits requires a complete transformation of how we design and build, particularly in our relationship with materials. The Australian Reduction Roadmap demonstrates that to align with the Paris Agreement's legally-binding 1.5–2.0°C pathway, emissions for Australian housing must fall by around 98 per cent. This is not an incremental adjustment but a reconfiguration of the industry itself. At the same time, Australia faces political pressures for rapid housing delivery. If delivered via '*business as usual*' this demand alone would consume Australia's entire national carbon budget (Crawford et al 2025).

We have to resolve these systemic challenges rapidly. Circle responds to this by situating materials as the core of system transformation. By evaluating not just emissions but the circularity, ecological impact, and viability of construction materials, Circle offers a lens through which we might glimpse a built environment that works within planetary boundaries.

Yet our capacity to understand the environmental impact of construction remains limited by the tools we use. Lifecycle assessment, embodied carbon calculations, and operational energy models have become the dominant measures of sustainability. But they only trace part of a material's story. They reduce complex cultural, political and ecological relationships to a single unit of account: 'carbon'. This is useful for comparison, but insufficient for understanding the broader consequences of how, what. and why we build.

While carbon metrics are indispensable for mitigating climate change, they cannot capture the full spectrum of environmental degradation. A building may perform well against industry sustainability frameworks traditionally focused on operational performance, yet its materials are likely to depend on extractive industries that destroy soil health, pollute waterways, degrade biodiversity, and damage communities. These impacts speak to the entanglement between material production, political economy, ecological health, and the rate at which matter can regenerate, circulate, and decompose.

Construction today operates largely within a linear model of extraction, manufacture, use, and disposal. As Malterre-Barthes (2025) makes abundantly clear, there are few greater challenges than the construction sector—and thus few greater opportunities to resolve our relationship with the environment we are part of.

> To build is also to destroy. To construct anything sets a series of actors, events, and transactions with harmful consequences in motion.
> Charlotte Malterre-Barthes (2025)

To drive towards a regenerative model, by actively and urgently resolving these *"harmful consequences"*, we must consider not only emissions, but how matter moves through and beyond human systems. This includes questions of renewability, reparability, toxicity, and it end-of-life potential. *Can a material be repurposed or returned safely to the environment? Does its production sustain or diminish the conditions for life? Does this building make our soils healthier or not?*

Evaluating materials in this way requires a reframing of what constitutes performance. Durability, strength, and efficiency remain essential, but they must be held in dialogue with cyclical and ecological parameters, how long materials last, and how they are disposed of. To pursue productivity gains without a more meaningful strategic counterpoint will only makes things worse. Efficiency and productivity cannot be treated as goals, just as growth cannot be treated as a useful target in itself—they have *directionality*, and our means to an end. They must not be seen as ends in themselves (Tronto 2015, Mazzucato 2023). Productivity is only relevant if it is an engine directed by the more urgent agendas represented in the Circle framework: regenerative circularity, zero emissions, and minimal ecological impact. Without these planet-aligned outcomes setting the scene, productivity gains translate to increased emissions and increased social and ecological damage—just more rapidly and cheaply. In this sense, buildings are not an end in themselves either, but an enabler of broader systems, aspirations and imperatives.

This perspective recognises that architecture is part of larger planetary systems, where every product, surface, and structure participates in wider exchanges of energy, matter, culture and economy. This entanglement is what makes architecture and construction so damaging when practiced without care. Equally, it is what might make it so meaningful, if transformed. Yet put bluntly, without that transformational change of direction, architecture and construction in Australia is simply a sub-sector of the mining industry.

We believe it can be something other than this, in line with many others (see *Reading List*). Circle responds to this expanded field of concern by pulling focus onto a diversified palette of enriching and valuable materials. It builds on existing emissions accounting methods while extending them to include circularity, ecological health, and long-term compatibility with natural systems. It attempts to sidestep the trap of overly-quantified approaches to inherently complex systems by suggesting other ways of thinking and acting. Its heuristic allows better questions to be asked of the complex interplay between materials and buildings. By seeing architecture and construction as embedded in material flows, we begin to see not only building's footprint, but its ongoing relationship to the environments that sustain it, and us.

Matter matters

Materials are the essence of construction, shaping not only the physical qualities of buildings but also their environmental and cultural footprint. Materials determine how built structures manifest themselves, how they perform, how long they last, how they might be adapted, and ultimately what happens when they are no longer needed. Every decision about a wall, floor, or façade is a decision about landscapes and ecosystems, labour and land-use, emissions and atmosphere—and therefore future environments, future societies.

Circularity begins and ends with materials. It is by their material flows that systems can be understood to be regenerative or extractive. Bio-based materials such as hemp, straw, or timber can be renewed through cultivation, but their environmental potential depends on how they are grown, processed, combined, and maintained. Geological resources like stone or earth can be reused almost indefinitely, provided they are produced, handled, and maintained carefully. Industrial products such as glass, steel, and aluminium embody a narrower form of circularity, having the potential to be recyclable at scale. But research indicates that such materials are rarely recycled in sufficient volume, even in societal settings legally incentivised to do so (Savini 2025). Their production processes remain heavily energy-intensive either way.

As operational lifecycle emissions decrease proportionally over time due to energy efficiency advancements, the contribution of embodied emissions related to the construction of new buildings increases. As noted, without significant transformation in our approach to these embodied emissions—not least through different material choices—net-zero targets will not be achieved (Röck et al, 2020).

Material choices embody the trade-offs that define construction today. Some materials excel in terms of durability but perform poorly at end of life. Others can compost safely back into the biosphere but may demand additional protection when in a building, and very different processes and supply chains. The broader tension between short-term industrial efficiency and long-term ecological responsibility is made manifest in the materials with which we make our built environment.

Yet by directly addressing the complex qualities of these material flows and processes, it possible to imagine a different form of construction. By examining design and construction through the lens of materials, we might move from abstract goals to systemic transformation. Understanding how materials are grown, quarried, processed, assembled, and disassembled reveals where circular pathways exist and where they are blocked. It also demonstrates that innovation in construction is not only about design or technology, but about re-establishing reciprocal relationships between matter, industry, and ecology. Materials become both the medium and the measure of whether our environment can exist within planetary boundaries.

Regarding any building. we might recognise that the materials that produced that building existed before it and they will exist after it. The building merely represents a moment in time, when its materials were frozen into a particular form, at that point. That moment may last 20 years or 200, but the materials themselves are part of effectively eternal flows of matter. Architecture, engineering, and construction has been oriented almost entirely around that 'frozen moment', at the expense of those material flows. It is time to redraw this diagram, reorienting practice around those material flows over time.

Dark matter matters

Tangible material is shaped by intangible forces: planning regulations, building codes, industry standards, fiscal policy, interest rates, investment logics, management processes, organisational models, software, education and training, cultural practices, and so on. With the built environment in particular, we might see and sense its matter—the building, in its material outcomes—yet what is built, and how, is in large part defined by these unseen forces, which Hill (2012) describes as 'dark matter'.

This means that, for all of the innovation potential of the private commercial sector, the *direction* of building is set by the public—by the dark matter of policy, regulation, standards, guidelines, and market design (Mazzucato 2023; Hill 2025). Evidence suggests that the built environment industry is unlikely to transform itself—it not on track to achieve decarbonisation by 2050, during which time our emissions budgets are likely to have been used up many times over (UNEP 2022; zu Ermgassen et al 2022; Mazzucato and Hill 2024; Crawford et al 2025). As Napiontek et al (2025) note, assessing Germany's building sector, *"technology improvements are not sufficient to reach climate targets (reinforcing the) need for housing policies that go beyond simply increasing the supply."*

Innovation in 'dark matter' can redirect the sector towards common good outcomes. For example, the Australian Reduction Roadmap is explicit about the urgent need to revise the national building codes to fully incorporate recognition of planetary boundaries implied by the legally-binding Paris Agreement (Crawford et al 2025). This would be following an agenda increasingly set by many other similarly wealthy countries—those with the biggest carbon debt (Amies 2025). Reduction Roadmaps position building codes as creative and equitable toolkits, such that building themselves might be reoriented around the biomaterial choices clearly suggested by the Circle framework. Currently, however, Commonwealth Government policy suggests an effective reversal on this front, freezing any emission-related revision of national building codes, perhaps unaware of the environmental impact of current policy settings (Hill 2025).

Inspiring examples exist elsewhere. After several years of industry-led advocacy, the Danish Reduction Roadmap movement prompted the Danish Government into the world's first embodied emissions ceiling for new buildings, and directly inspired and informed the Australian version. In France, regulations directing that all new public buildings must be at least 50 per cent timber or equivalent biomaterial has led to a reinvention of the architecture, construction and forest-wood sectors, reoriented around mass timber (Leloup et al 2022). Though far from perfect, these are increasingly integrated approaches, working simultaneously with supply and demand, public and private sectors, matter and dark matter, people and place.

Regarding retrofit, the Regional Urban Planning Regulations of the Brussels–Capital Region states that *'Every existing building will be conserved and, if necessary, renovated'* (RUPR 2024; Van Gerreway, C. 2025b). The City of London's *RetrofitFirst* policy encourages the reuse of existing buildings alongside other circular economy measures (Hirst 2025) as does Westminster Council's new policy (Butler 2026; Westminster Council 2026). In our discussions with them, GXN noted that these policies have already transformed their London-based practice, just as Kaminsky Arkitektur speculated that most of their future work is likely to be retrofit of existing buildings and places.

'Upstream' innovation in dark matter by public designers of public code must create the conditions for this inventive downstream practice to thrive.

Research approach

Given the relatively short project duration, the research team focused on desktop research complemented by a series of discussions with industry and research partners. For this Building 4.0 CRC project, we were fortunate to have a core industry partner in **Lendlease**. We added a range of further discussions with contacts from our networks (right), in particular with a diversity of architecture and design practices.

We also had a wider set of conversations around the project. With Arup, we discussed Circle, and its forerunner of Reduction Roadmap, in London (25–06–25) as well as during meetings for the Laudes Foundation-supported project *Homes That Don't Cost The Earth* project led by University College London's Institute for Innovation and Public Purpose, Arup, and Dark Matter Labs. We also discussed Circle's core themes in meetings with Ellen MacArthur Foundation (08–05–25 and 16–06–25), BuiltByNature (23–05–25), and Victorian Government Department of Energy, Environment and Climate Action (29–05–25).

Additionally, Circle has been presented at a wide range of events (see *Appendix 2*). Discussions at these events have also informed this project.

A working group from the Faculty of Architecture, Building and Planning at the University of Melbourne was set up for the project, featuring a diversity of built environment disciplines, principally from architecture and construction. This group included Xavier Cadorel, Christhina Candido, Adrian Chu, Sofia Colabella, Robert Crawford, David Fedyk, James Helal, Melinda Heron, Dominik Holzer, Rory Hyde, Nancy Ji, Jas Johnston, Brendon McNiven, André Stephan, Katie Skillington, Djordje Stojanovic, and Alan Pert. The group met several times, across different formats and themes.

Two workshops were held with Lendlease, bookending the project: a Sydney kick-off workshop featured around 25 participants, representing multiple different aspects of Lendlease's business, followed by a Melbourne-based workshop, featuring online participants from Sydney, which discussed project findings.

Durra Panel was selected as perhaps the best-known of the circular product manufacturers in Australia, having demonstrated an ability to scale and consolidate its business in strawboard panels.

From architecture, we selected a diversity of practices in terms of scale, location, and focus. Each had particular insights with aspects of circularity. Noting that the built environment sector in Australia is heavily influenced by the positioning of developers, and that many other Building 4.0 projects focus on construction industry, we have emphasised the pivotal role of architecture instead with this project, recognising the need to radically transform practice at the point at which material interventions are imagined and devised. A study visit to the Royal Danish Academy's CINARK group enriched and confirmed this perspective.

Insights from these discussions are woven throughout. Finally, Circle is part of a broader strategic portfolio following the *Australian Reduction Roadmap*. We note the ongoing contributions made by Terroir/QUT's Gerard Reinmuth and Terroir's Mikkel Møller Roesdahl to the thinking here, alongside that of various other Danish colleagues (listed in Crawford et al 2025).

The Building 4.0 CRC Project Milestone Final Review meeting was held on 19–12–25.

Industry discussions

Development

Lendlease

Workshop 1 Sydney 03-06-25; **Workshop 2** Melbourne 12-11-25

Global real estate and property investment business, headquartered in Australia. Workshops focused on systemic challenges of a circular built environment.

Manufacturing

Durra Panel

Discussion 1 Online 19-12-26

Strawboard-based panel product manufacturer, largely for interior fit-out. Discussion focused on potential for industry transformation via product development.

Architecture and design

GXN

Workshop 1 Online 29-10-25; **Workshop 2** Copenhagen 10-12-25

Global architecture and research practice, headquartered in Copenhagen and linked to 3XN. Workshops focused on retrofit and material innovation possibilities.

Fieldwork

Discussion 1 Online 13-11-25

Melbourne-based architecture practice. Workshops focused on structural timber, retrofit, and circular material products for fit-out.

Waugh Thistleton

Discussion 1 Online 15-10-25

London-based architectural practice. Discussion focused on timber buildings and systemic approaches to wood supply chains.

Hassell

Discussion 1 Online 11-11-25

Global architecture and design practice, headquartered in Australia. All-round expertise. Discussion focused on circularity in fit-out and systemic change in industry.

Kaminsky Arkitektur

Discussion 1 Online 12-01-26

Stockholm and Gothenburg-based architectural practice. Designers of world's tallest straw building. Discussion focused on design with biomaterials.

Public Realm Lab

Discussion 1 Online 11-11-25

Melbourne-based architectural practice. Designers of first public hemp masonry buildings in Australia. Discussions focused on systemic approaches to bio-based materials.

Research

Centre for Industrialised Architecture (CINARK), Royal Danish Academy

Study visit Copenhagen w/c 08-12-25

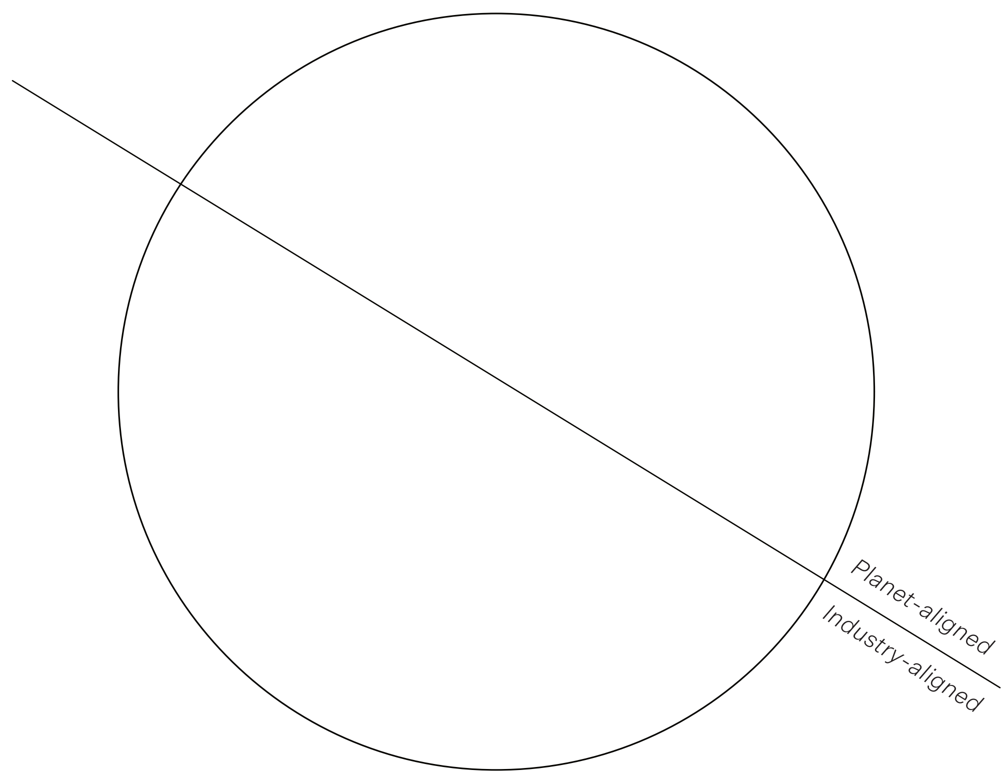
Study visit to CINARK, discussing innovation in locally-sourced regenerative biomaterials for circular construction, architecture and design.

Faculty of Architecture, Building and Planning, University of Melbourne

Workshop 1 Melbourne 06-10-25; **Workshop 2** Melbourne 22-10-25

Cross-disciplinary team from University of Melbourne, assembled for Project Circle. Discussions focused on lifecycles, industry transformation, and education.

The Circle framework

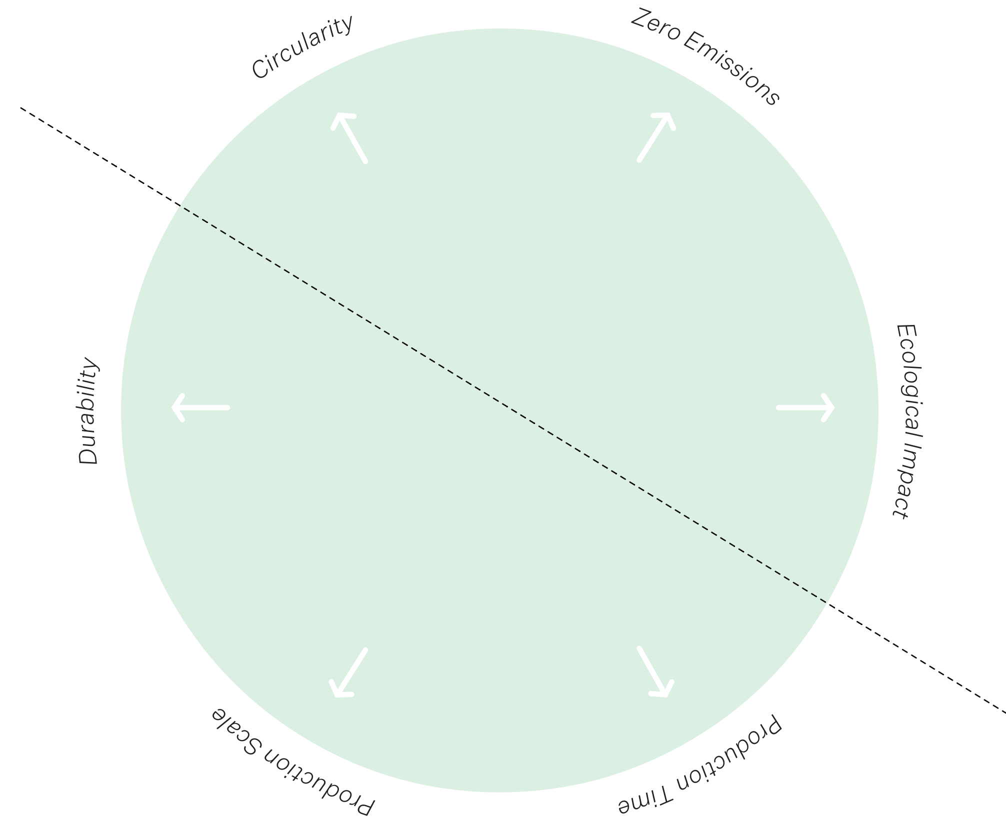


Materials are where abstract sustainability goals meet tangible decisions and outcomes: they embody greenhouse gas emissions, determine waste streams, shape land-use, degrade or enhance biodiversity, create rewarding jobs or dangerous quality work, and set the pace, scale and possibility of building itself. To make these interdependent trade-offs visible, Circle evaluates ten materials through six criteria.

Three of these criteria are described as **planet-aligned**, encompassing the elements **circularity, zero emissions**, and **ecological impact**. These three high-level criteria draw largely from the planetary boundaries framework. As defined by the Stockholm Resilience Centre, that framework has nine interdependent boundaries, each of which must stay within a 'safe operating space' (Rockström et al 2009). These boundaries describe the *"safe limits for human pressure on these nine critical processes"*, taking a quantitative measure of aspects like CO2 concentration, ozone depletion, freshwater use, biosphere integrity, and so on. The latest review of the framework, the *Planetary Health Check 2025*, finds that seven of the nine boundaries have now been crossed (Planetary Boundaries Science 2025). As the built environment is our most extractive sector, this finding underscores the imperatives behind positioning **planet-aligned** aspects so clearly the Circle framework. Rather than simple formulae, the three elements selected—*circularity, zero emissions*, *ecological impact*—are in effect high-level 'umbrellas', encompassing many aspects of the planetary boundaries. Abstracting in this way is not only about simplifying a visualisation, but purposefully shifts away from a purely quantifiable, metrics-based approaches to the complex questions of sustainability, recognising some of the issues embedded up in that otherwise valuable perspective (Petersen 2024, 2025).

About the circle

The Circle framework is visualised as a circle, with scores loosely implied for each of six criteria. A 'good result' for a material would be a full circle, with a high 'score' on each aspect suggesting a holistic sense of value.



The other criteria are more obviously **industry-aligned**, oriented around factors of **production time, production scale, and durability**. Whilst these simple frames also hide significant complexity, they describe the realities of building demand and performance, as well as typical industry imperatives for cost reduction, driven by efficiency in construction and operations.

This dual lens, deliberately playing off current industry imperatives against those of the planet, implicitly acknowledges that any pathway to circular construction must balance planetary limits with industrial viability, positioning materials as the critical leverage point for systemic change. As with planetary boundaries more generally, our challenge is that we have tended to prioritise industry-aligned metrics over planet-aligned metrics. Yet whilst there are pockets of good practice across the architecture, engineering and construction sector in Australia, there are currently no regulatory or policy structures or processes that meaningfully bring together industry-aligned and planet-aligned perspectives in favour of planet-aligned outcomes. In fact, we argue that practices currently skew towards industry-aligned outcomes. Given the impact of the built environment in particular, we have neither time nor material budget to allow this 'business-as-usual' to continue. As with other societal goals, our shared agenda must be to ensure that **industry-aligned and planet-aligned ultimately become the same thing, oriented firmly around the safe operating space**. We must achieve strong results in all aspects of the framework, simultaneously.

Defining criteria and materials

The Circle framework evaluates construction materials against six criteria, structured into two sets—planet-aligned and industry -aligned. Evaluating materials across criteria such as **circularity, zero emissions, ecological impact, production scale, production time,** and **durability** is essential because it provides a broader understanding of performance than greenhouse gas emissions alone. These criteria combine to convey a sense of inherent performance for the material, which we extend to describe different outcomes for building elements and assemblages based around those materials.

Clearly, any atomised categorisation of complex, holistic, living systems and flows is inherently reductive (McGilchrist 2019). We resist such an over-simplification in favour of an abstract indication of such performance, conveyed as a loose visualisation. Yet we also see the value in beginning to broaden how materials are comprehended, and ultimately selected and designed with, and we recognise the possibility in co-opting, and to some extent 'hacking,' the typical working language of a sector overly attuned to quantitative metrics.

This dual structure acknowledges that materials must perform both environmentally and industrially. Grown biomaterials such as hemp or straw score highly on carbon and circularity but face challenges of scale and durability. The production of highly extractive yet long-lasting materials such as steel and concrete has been optimised in terms of speed and scale, but fatally undermine planetary boundaries through emissions, waste, and broader impact on ecosystems and communities, as is powerfully described by Malterre-Barthes (2025). By visualising and scoring each material through spider diagrams and process maps, Circle makes such trade-offs visible and locates opportunities for innovation in the 'uncharted' areas of the diagrams, indicating where work is to be done. As noted, by allowing us to clearly describe planet-aligned characteristics, the framework allows designers and others to skew their choices in this direction. The Circle framework's simple visualisation foregrounds this choice. We are clear that, ultimately, material choices must start and end with planet-aligned outcomes, and bend industrial practices in that direction. The framework can be used to provoke and support the discussions needed to move 'absolutely' towards **planet-centred innovation** (Mossin et al 2023).

The framework's six criteria are applied to a set of ten typical materials, allowing us to present those as, loosely, planet-aligned (**hemp**, **straw**, **timber**, **stone**, and **earth**) or industry-aligned (**concrete**, **steel**, **glass**, **brick** and **plaster**). Although all these materials are well-known, the more obviously planet-aligned set are far from mainstream, whilst the current industry's mainstream is far from planet-aligned.

Whilst this immediately obvious in terms of embodied emissions, six criteria help move evaluation beyond a singular focus on 'carbon'. While reducing embodied and operational emissions remains fundamental, the transition to lower-impact construction also relies on how well materials circulate, how quickly they can be produced, how they interact with landscapes and ecosystems, and whether they can deliver long service lives without intensive maintenance or replacement.

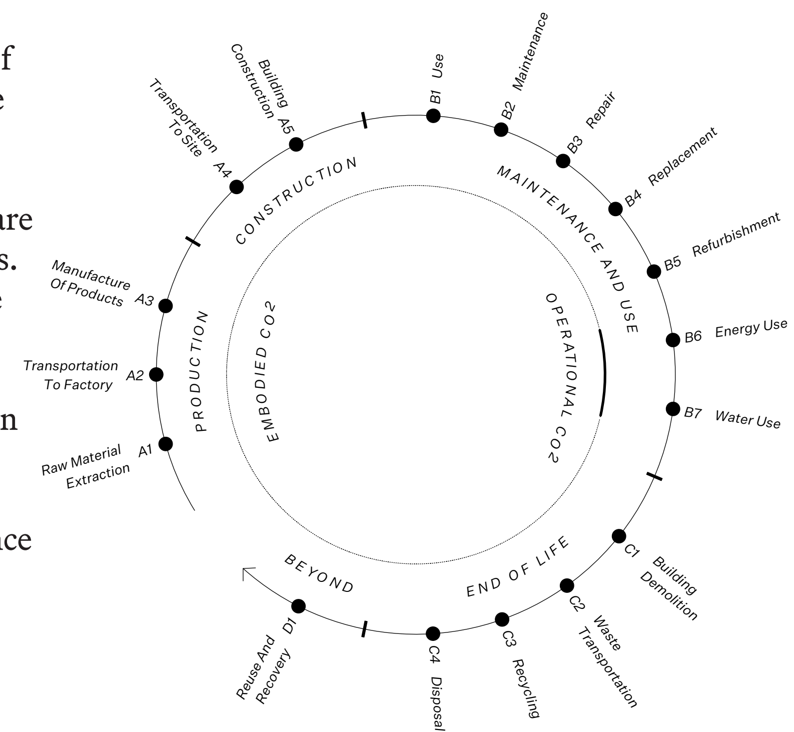
Even this expanded framework contains ambiguities and unknowns. A material might be theoretically recyclable, yet research indicates that recycling rarely occurs in practice (Savini 2025). There will be large differences in impact depending on whether a disassembled and re-used material element is returned to the biosphere (for instance, hemp or straw returned carefully to healthy soil) or retained in the technosphere (for instance, existing

concrete panels modified and re-assembled for a new building). The industry has few practices and policies in place to direct these outcomes. We are aware that such questions represent only the tip of an iceberg of complexity, and have taken the decision to draw the line at relatively high level, producing a method which might be refined and extended in future programs. As we will note, we are aware that there are far more than six criteria regarding material choices. We still believe that this 'v1.0' framework is capable of being used as a useful heuristic for asking better questions.

The criteria used only become meaningful when assessed across building lifecycle stages (see diagram, right): from product sourcing (A1–A3) through construction (A4–A5), use and maintenance (B1–B7), and end-of-life scenarios (C1–C4), culminating in opportunities for reuse, recovery, or recycling in stage D.

In reality, materials flows are more ambiguous than these traditional lifecycle diagrams. Circularity depends on what 'end of life' might mean. Durability relates to care and maintenance requirements throughout the operational phase and lived experience of a building, and might have completely different outcomes and imperatives, depending on context. Evaluating materials holistically across these stages ensures that decisions address not only emissions, but also long-term system impacts and the practical realities of delivering a viable and meaningful, low-impact material future. Each of these criteria is defined and described in more detail overleaf.

Typical building lifecycle



Circle framework criteria

PLANET-ALIGNED

Circularity
The extent to which materials can be reused, recycled, or biodegraded without residual waste.

Zero Emissions
The extent to which materials can approach zero embodied emissions from extraction, processing, delivery and installation.

Ecological Impact
The extent to which material processes can align with planetary boundaries, including biodiversity, land use, and pollution.

INDUSTRY-ALIGNED

Production time
The extent to which material sources can be quickly replenished or manufactured.

Production scale
The extent to which global or local systems can source and produce the material at scale.

Durability
The extent to which materials retain high durability over their lifespan and performance in construction, before replacement.

1

Circularity

CIRCULARITY is a measure of whether a material can remain in productive use across multiple lifecycles, avoiding waste and landfill. It includes direct reuse, recycling, downcycling, and biodegradability. A high score for circularity indicates that a material can cycle back into use without losing value or creating environmental burdens. **HEMP**, **STRAW**, and **EARTH** tend to rate well here because they can decompose naturally or be reintegrated into soil systems—known as returning to the biosphere. **TIMBER** can also return to such biological cycles with minimal emissions if handled carefully, or it can be reused in structural form if designed-for-disassembly or, with some reworking, be reused for building elements in subsequent buildings. **STONE** and **BRICK** perform strongly when dismantled and relaid, maintaining strength across centuries of reuse. **STEEL** is endlessly recyclable, at least in theory, allowing for repeated recovery and reforming, which is a notable strength of such metals. Of course, there are environmental costs to this additional processing and as noted, there is little evidence of recycling happening in mainstream practice at any significant scale. This is particularly the case with buildings, as compared with other sectors, due to a lack of regulation around end-of-life producer responsibility and fragmented business processes, dislocated material cycles, and a legacy of lacking incentives. **GLASS** and **PLASTER** can also be recycled, but contamination or coatings often reduce rates of success. **CONCRETE** typically ends up downcycled into aggregate, representing lower-value forms of reuse.

Balancing these aspects of 'potential versus reality', and not discounting the significant, often hidden costs involved, an evaluation of circularity allows us to broadly highlight which materials align with generalised circular economy principles and which are likely to lose performance or quality after use. As with all other criteria, circularity must be evaluated holistically, in the round.

2

Zero emissions

ZERO EMISSIONS is an evaluation of the greenhouse gases generated across all stages of a building material's lifecycle, and in doing so brings traditionally-neglected embodied emissions to the fore. A high score indicates that a material has relatively low embodied carbon emissions per unit of use. **HEMP** and **STRAW** perform well, as they are agricultural by-products that require minimal processing and store carbon during growth. **TIMBER** also performs well, as managed forests can sequester carbon over a material's life, though its overall emissions depend on the energy used for drying, milling, fabrication, and transport. **STONE** has a lower embodied emissions impact than concrete when used structurally, as it requires no high-temperature processing, though it remains higher than timber due to extraction and cutting. Many **EARTH**-based products, such as rammed earth or compressed earth blocks, require little processing or firing, resulting in very low embodied emissions when locally sourced. In contrast, **CONCRETE** has high emissions due to the energy intensity of cement production. **STEEL** carries a significant footprint from smelting and refining, although recycling reduces its impact. **GLASS** and **BRICK** have moderate emissions from high-temperature furnaces and kilns, while **PLASTER** sits lower, as its calcination process is less energy-intensive.

There are further issues with this criterion. Perverse outcomes lurk within simplistic quantification i.e. per m² calculations for embodied emissions may inadvertently preference larger house sizes, with their rooms' large volumes reducing the *ratio* of emissions per square metre—yet producing more emissions overall. More profoundly, Petersen (2024, 2025) critiques overly quantified approaches to a *"numerical environmentalism"* in general. This latter perspective has directly informed this work, yet we still pragmatically retain a 'score' for emissions. The framework's visualisation is rendered deliberately loosely, as a result, suggesting a heuristic for asking better questions with rather than a formula for calculating a precise, objective answer.

3

Ecological impact

Following this discussion of overly simplistic approaches, environmental sustainability has often been reduced to a question of greenhouse gas emissions. Whilst emissions are intrinsically important, a more systemic definition would see material impacts situated within the *Planetary Boundaries framework*, as outlined by Rockström et al (2009), identifying the 'safe operating space' for humanity across Earth systems processes including land-system change, freshwater use, biodiversity loss, and biogeochemical cycles. Further, these ecological impacts are related to questions of social justice, labour, economic livelihood, and colonialism (Malterre-Barthes 2025). As a result, the framework must equally address the **ECOLOGICAL IMPACT** of construction, particularly the 'upstream' embodied emissions in extraction and production. A high score indicates that a material can be produced with low disruption to these planetary systems—in other words, the material choice has, potentially, a low ecological impact. **HEMP** and **STRAW**, as crop by-products, generally perform well when integrated responsibly into existing agricultural cycles. **TIMBER** scores highly when harvested through sustainable forestry, though unsustainable logging or poorly managed plantations can compromise ecosystems and biodiversity. **EARTH** and **STONE** can often be sourced locally and, when extracted responsibly, remain within boundary limits, though quarrying and excavation still alter landscapes. Yet **CONCRETE**, **STEEL**, **GLASS**, and **BRICK** all involve industrial processes with high resource intensity, intersecting strongly with land-use change, biodiversity loss, soil and water degradation, pollution, and diminished nutrient cycles. **PLASTER** requires gypsum extraction but at lower intensity than some alternatives. Evaluating ecological impact, largely through the lens of the Planetary Boundaries framework, broadens assessment beyond emissions, emphasising each material's role in maintaining Earth's stability and ecological health.

> Architecture that connects with nature makes full use of ... local resources. By harnessing sunlight and natural ventilation, it is possible to reduce energy consumption from mechanical systems during operation, create a comfortable thermal and lighting environment, and remain functional even when urban infrastructure is disrupted by disaster. Using local soil and wood with minimal additives allows for material reuse and eventual return to the earth. This reduces the energy associated with material extraction, construction, demolition, and disposal, and produces warm, human-scaled spaces made from natural materials. If we build in a way that respects or regenerates the site's topography, water flows, and subsurface ecology, we can reduce disaster risks. Moreover, if we create environments where diverse plants, animals, and even microorganisms can coexist, we can help restore biodiversity—contributing not only to disaster resilience and climate mitigation, but also to reducing the risks of infectious diseases and psychological stress in humans.

Nori Kawashima
Towards A Delightful Architecture With Nature: Nori Kawashima Works (2025)

4

Production time

Given the need to rapidly transform the existing built environment, how quickly a material can be replenished or manufactured within an Australian context is an important factory. Equally, the relatively poor productivity within the construction sector means that industry prizes a material's ability to be produced rapidly. A high score for **PRODUCTION TIME** indicates short production cycles or immediate availability based on existing infrastructure and supply capacity. **STRAW** performs well, as Australia produces large quantities annually as an agricultural by-product, making it readily available for use in construction with minimal adaptation of current systems. **HEMP**, by contrast, grows quickly but lacks established processing infrastructure such as decorticators to separate the hurd from the fibre, limiting its short-term scalability despite its biological potential. **TIMBER** requires years to decades to mature—and centuries for a meaningful forest to be established—yet Australia's established forestry sector can provide a steady and reliable supply when forests are managed sustainably. Further research is needed here, to assess what might actually be possible, and required. **EARTH** and **STONE** are already abundant and locally available across most regions, needing minimal processing, and therefore score highly for immediacy of access. **CONCRETE**, **STEEL**, **GLASS**, **BRICK**, and **PLASTER** can all be manufactured rapidly, as industrial supply chains have been optimised over the last century, reflecting a the focus on efficiency of existing systems, albeit at the expense of planet-aligned factors in the framework. This category isolates time as its key variable, separate from emissions or ecological impact, revealing how availability depends not only on biological growth cycles but also on the legacy investments in industrial and logistical infrastructure supporting material production.

5

Production scale

PRODUCTION SCALE relates to the readily available scale or volume of a material's reserves, and its supply chains, in order to meet construction demand. High scores mean established infrastructure, widespread production, and proven networks. **CONCRETE**, **STEEL**, and **GLASS** tend to dominate production systems here: they are globally standardised and produced in vast volumes. **BRICK** and **PLASTER** also perform strongly for this aspect of scale, with large industrial networks supporting their availability. **TIMBER** benefits from extensive forestry supply chains in many regions, though overall capacity is linked to forest management, and such reserves have rarely been managed with the need for timber to act as a large-scale replacement for, say, concrete or steel—at least under current Australian policies. **HEMP** and **STRAW** are produced at agricultural scale, and as a side-effect, we effectively already produce enough material to supply a significant proportion of a biomaterial-led construction industry, but currently both face challenges in processing and integration into mainstream building markets, in terms of awareness, infrastructure, and the 'dark matter' of building codes and land-use policy. **EARTH** and **STONE** are also abundant of course, but their provenance tends to be localised, with scalability limited by transport logistics, and they face similar issues in terms of barriers to mainstream adoption. Evaluating production scale highlights how infrastructure, markets, and supply systems enable or constrain materials. It clarifies why some dominate globally while others remain regional, and it points to where investment in supply chains could increase the role of circular or bio-based alternatives. Equally, it is held in tension with the need to meaningfully assess how much scale we actually need. In other words, despite current headlines and policy directives, the industry already tends to over-supply buildings, including housing, in countries like Australia (Hill 2025). As we note in the conclusion, a better starting point for production scale would be an assessment of need and demand, rather than a mono-focus on supply.

6

Durability

How durable a building element is depends on how long a material performs in use before repair or replacement, considering resistance to weathering, fire, and structural fatigue. A 'high score' for **DURABILITY** indicates longevity and low maintenance requirements.

STONE and **BRICK** tend to perform very strongly, with proven lifespans of centuries. **STEEL** is also long-lasting, particularly when protected against corrosion and fire. **CONCRETE** has good durability, although corrosion of reinforcement can limit its lifespan in certain conditions. **GLASS** is durable in a sense, though of course can also be brittle, depending on its assemblage and context. **TIMBER** performs well when protected and detailed appropriately, though is more vulnerable without treatment. **HEMP**, **STRAW**, and **EARTH** require careful protection from the elements, but under the right conditions can also last for decades or more, and their durability depends on how they are assembled and whether they are exposed i.e. our discussions around the Hyllie building in Malmö suggests that the architects see no particular issue with the longevity of the straw cassettes, as they are protected by a more durable materials, indicating the importance of assessing how materials form assemblages in buildings. (The Circle framework offers a way of understanding the likely performance of typical assemblages, as well as a material's inherent properties.) **PLASTER** is the least durable, degrading quickly under moisture or impact.

Evaluating durability highlights how materials align with longevity, informing care and maintenance cycles, replacement needs, and the resilience of construction systems over time,

> As soon as you take a blood test, you can identify what is happening. It becomes very tangible. I think this is like the tangibility, the scrutability of architecture. I want the building to tell its own story through the voices of its materials. You can see how things are being connected, and you can see the logics of things ... The more you do that, the more the house communicates to you, and the more provocative the architecture becomes.

Søren Pihlmann
Making Matter What Too Often Does Not Matter, Søren Pihlmann and Adam Dickinson (2025)

A further note on durability

In discussions, durability was often the most ambiguous criterion in the Circle framework, with different interpretations of its importance.

Traditionally, a more durable material might be an almost instinctive preference, reducing maintenance costs and making embodied emissions 'work harder', by spreading the multiple costs of extraction and production over a longer time period. In terms of embodied missions, conventional lifecycle thinking might effectively amortise the greenhouse gas production over time i.e. if a concrete building lasts hundreds of years, which it might, the significant environmental impacts of its embodied emissions is theoretically lessened, as that 'cost' can be divided by the number of years the building exists. This is even how many progressive policy approaches work, such as in the Danish building code changes encouraged by the Reduction Roadmap movement (Reduction Roadmap 2024)

There are two issues here. The first is that existing climate action policies direct us to make significant differences in the very short term i.e. the immediate next decade or two, with some policy directives, such as the Global Goals, set for 2030, and other national targets to be achieved by 2045 or 2050. The imperative for these immediate goals is to address the build-up of emissions in our atmosphere now, noting that the danger of not doing so may be additionally compounded by unpredictable and irreversible feedback loops. In terms of buildings, these embodied emissions are in the atmosphere from what is effectively year zero for the building i.e., during the upfront production process, and continue to exist there for every subsequent year. There can be no 'amortisation' of these emissions, in other words. This was addressed in the Australian Reduction Roadmap, in discussion with the authors behind the original Danish roadmap (Crawford et al 2025)

The next decade of building is imperative in terms of environmental impact, which means that the long term durability, and lifecycles, of otherwise extractive materials could be seen as largely a moot point. In effect, it would be continuing to let aspects of the industry 'off the hook' by allowing them to discount the future, in the language of climate action policy, by continuing to use legacy materials of concrete and steel as opposed to lower-carbon and lower ecological impact alternatives such as timber and stone, both of which can also be highly durable.

As a result, the Circle framework enables us to propose skewing our material choices towards certain planet-aligned criteria—zero emissions, ecological impact and circularity. This allows us to bring a more diverse range of strategies into play, from 'not building' and retrofit through to industrial transformation, based on exerting a material budget for all remaining building.

The second issue concerns the program, or intended purpose, of the building. A deliberately temporary building need not be highly durable, just as a temporary element of a building need not be—depending on what happens to the materials next. Whereas, a civic building designed to last several hundred years, say, might prize highly durable materials and assemblages. This aspect foregrounds questions of maintenance, care, operations, adaptation, and the material's life after buildings.

A shift in design and building practice is required. Japan's Ise Temples have lasted for 1000 years by virtue of being completely rebuilt every 20 years, partly enabled through its material choice of timber for aspects of the temple complex. Other aspects are constructed with stone, at varying scale and mass, allowing for permanence. This interplay between *fixed and permanent* (high durability) versus *moving and adaptable* (low durability) is the essence of Ise. Timber's relatively lower durability, at least in this treatment of the material, is actually advantageous in this respect.

These 'moving layers' of the buildings allow for invention, adaptation, and innovation, a continual form of prototyping. In one of the most important architectural texts, Kenzo Tange foregrounded Ise's ability to challenge us with the question of *"the symbols of the present"*, seeing Ise as *"the prototype of Japanese architecture"* (1965).

Extending this sophisticated approach would equally draw from the well-known *pace layers* concepts of Duffy (1992) and Brand (1994), and expanded into the concept of *place layers* by Hill and Melander (2025). This would ask designers to more carefully consider durability as a versatile gradient, rather than simply defaulting to 'highly durable'. If a building is seen as a series of shifting material layers, spaces and programs, then we find a different relationship between materials (and their provenance), building, designer, and user. Indeed, a faster-moving layer of a building might be designed specifically to have a relatively lower durability.

This suggests that maintenance might be reoriented as *care* instead (Hill and Melander 2025)—thus a cost becomes an investment—which in turn suggests differing roles for architects and builders, different economic models for buildings, and different ethical models for practice (Chachra 2023, Petersen 2025).

> Instead of utilitarianism, then, we can draw on a different operative moral framework: the ethics of care.
> Deb Chachra (2023)

There are ways in which we might meaningfully extend thinking about durability, via analogies for thinking about shifting layers of buildings, and the interplay between biomaterial choices and different forms of care. In the conclusion, we outline a metaphorical approach to this—*'the cello and the garden'*—which describes two different approaches to practices of continual engagement, care, and adaptation. In doing so, it suggests ways of thinking about buildings.

Thus, unlike other criteria in the framework, where a 'high score' is almost always the goal, durability is perhaps more context-dependent. Equally, a full circle is still likely to be a meaningful goal: this would suggest high durability alongside low emissions, ecological impact and other criteria.

Yet the visualisation of the framework also allows low-durability to be a reasonable goal, dependent on context, and assuming other criteria are addressed coherently.

The periodic rebuilding of the Ise Shrine has by now been carried out fifty-nine times, or for more than one thousand years. Perhaps we can say that the distortions contained within the history covered by this long period are traced in deep shadows on the form of Ise, and have also left their marks, like the annual rings added to a tree, on the spirit of the Japanese people. But behind these shadows, the quintessential form of Ise has remained intact and alive, and the later history of Japanese architecture has never been able to advance beyond it. It has remained the prototype of Japanese architecture.

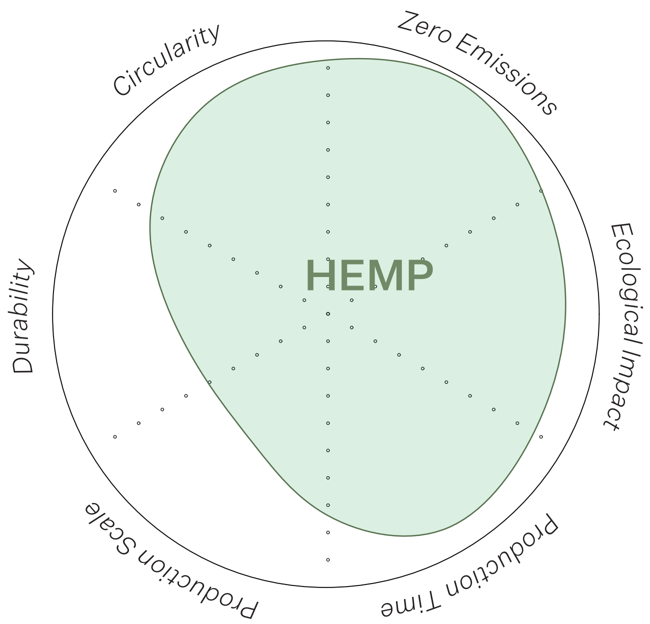
Kenzo Tange
Ise: Prototype of Japanese Architecture (1965)

A full circle, indicating high durability as well as high performance for all other criteria.

An indented circle, indicating purposeful low durability alongside high performance for all other criteria.

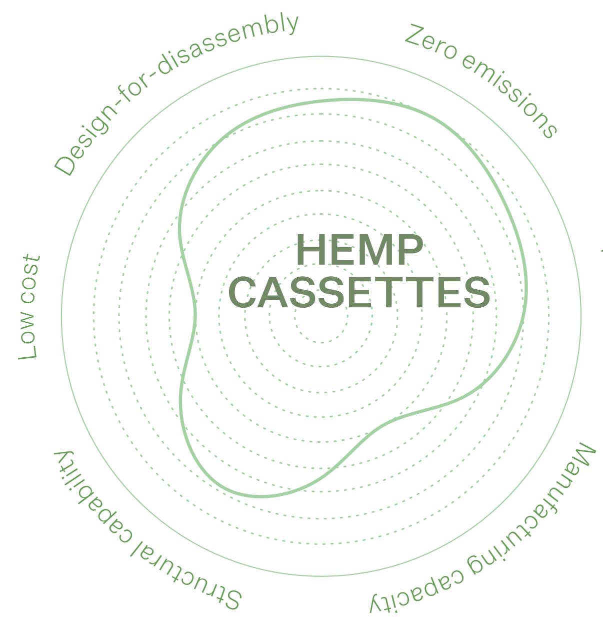
About the visualisations

Example material
Hemp



A **spider chart** allows a multivariate analysis of materials at-a-glance. Here, for example, we can assess hemp's performance against the Circle framework. A full circle would be performing well against all criteria. The 'shape of hemp' indicates its *particular* strengths. We can quickly see that hemp is attuned to the planet-aligned criteria of circularity, emissions and ecological impact. We can also see that its production time is appealing; as a crop, it grows rapidly. Production scale is lacking in Australia, however, and when used to produce building components it is not particularly durable, at least in terms of standard industry expectations. The diagram quickly indicates where innovation is required—production scale (depending how much demand is actually required) and diversified interpretations of durability when assembled into components.

Example material assemblage
Hemp cassettes



Of course, materials must be combined into components to be used in buildings. Buildings are **assemblages** of components, and building components are assemblages of materials. For each of the six materials selected to demonstrate the Circle framework, several typical assemblages have been chosen. Whereas a raw material is visualised in terms of its high-level capabilities and capacities, an assemblage can and must be evaluated differently. New criteria emerge, for a subtly different diagram. Again, these criteria can be seen as broadly relating to planet-aligned or industry-aligned concerns. The former denote **embodied emissions** in production, ability to **design-for-disassembly,** and **thermal** performance for insulation; the latter are the ability to **manufacture** at scale, its **structural** capacity, and a high-level estimate of its relative production **costs**.

Criteria for assemblages

A hemp cassette

Each material assemblage is assessed in terms of the following criteria, in order to describe the 'shape' of its performance. As before, the diagram describes its particular inherent strengths through its outline, and the areas for potential innovation in the space around, with both based on a reading of current industry capabilities.

PLANET-ALIGNED

Design-for-disassembly
The extent to which assemblage can be designed-for disassembly to allow for circularity

Zero Emissions
The extent to which assemblage can approach zero embodied emissions from production, delivery and installation.

Thermal
The extent to which assemblage has insulating properties, describing thermal performance.

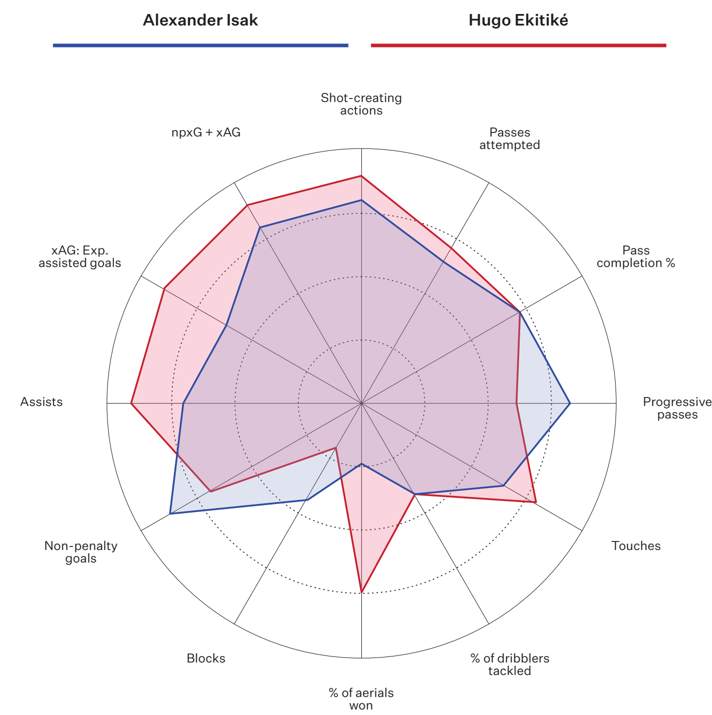
INDUSTRY-ALIGNED

Manufacturing capacity
The extent to which a production capacity for this material assemblage exists in Australia.

Structural capacity
The extent to which the material assemblage can be used as a load-bearing structural element in buildings.

Low cost
A high-level assessment of typical relative cost to manufacture this material assemblage.

Visualisation approach



Spider charts, or radar diagrams, can convey multivariate analysis at a glance (despite debates over their efficacy within the field of information visualisation, noting that *"small multiples"* may be equally worth pursuing, according to Tufte (1990)). Our diagrams resemble the well-known *Planetary Boundaries* diagram—although the Circle framework looks to 'fill the circle' as opposed to seeking to withdraw into the 'safe operating space'. More directly, inspiration was drawn from the popular visual language of sports data visualisations, such as the chart comparing two footballers above (redrawn from an original at FBCharts.com). Here, the 'shape of the better player' would also fill the circle. For Circle, we deliberately use a more organic drawing style to avoid a false sense of objective precision, noting as an aside that we seem to have far more data about footballers than buildings.

Extending the framework

SUBJECTS

Materials, structures

The Circle framework is initially illustrated via ten materials, five representing common 'industry-aligned' choices, and five typically associated with 'planet-aligned' choices. Clearly, orthodox construction practices use a vast range of materials, yet concrete, steel, brick, glass, and plaster were chosen for their sheer ubiquity, the extent of which illustrates the scale of the challenge.

The five planet-aligned materials selected are also ubiquitous, albeit not used at scale—yet. Clearly, there are many more 'novel' bio-based materials than the set chosen, each with exciting potential, such as mycelium, algae, seagrass, bamboo, or bacterial substitutes for cement. Yet the five selected are already largely 'at-hand', and with potential to be widely used, relatively rapidly.

More broadly, the Circle framework's initial task is articulate how its lens might be pointed at any material, or material assemblage, in order to prompt and support better questions. It is not to produce an extensive materials catalogue at this stage (versions of this already exist, albeit typically focused on narrower or singular sets of criteria). Circle's lens, particularly as it is refined over time, could equally be 'pointed at' eelgrass thatch, blue biomass bricks, mycelium interior walls, or 3D-printed nanocellulose.

Equally, bio-based materials can also be used in the context of infrastructure as well as buildings. For example, mass timber's ability to replace concrete and steel allows it to be used for road bridges (Thie 2021), data centres (Stora Enso 2025), and wind turbines (Aouf 2024), just as mycelium and agricultural straw by-product may be able to replace asphalt road surfaces (Visibuilt 2025). Again, the Circle framework could be extended to cover material and material assemblage choices for infrastructure too.

CRITERIA

Health and wellbeing

Any subsequent extension of the Circle framework could consider *'the extent to the material choice positively impacts human health'.* This would include health and wellbeing associated with construction-related labour—extending this from extraction through to manufacturing, installation, maintenance, and disassembly—potentially with significant impact. The UK's Health and Safety Executive report that construction, compared with all industries, has the highest rates of occupational cancer, musculoskeletal disorders, lung disorders, dermatitis, non-fatal injuries, and ill health caused by noise and vibration (HSE 2024). Other than asbestos, there is no mention of the impact of material choices in HSE's guidance. Yet the possibility of working with lighter, less processed, bio-based materials suggests different outcomes.

The materials described in Circle can also be assessed in terms of their health impact on building users. Our Faculty colleagues are leading significant work in this area, via our Sustainable Healthy Environments Lab: for example, recent research suggest that timber-rich environments produce positive health outcomes (Whyte et al 2025). Hariadi and Carlisle (2025) report similar findings, but both studies note gaps in the depth and breadth of studies, indicating further research is required. Impact on non-human living beings will also be relevant. Each of the 'planet-aligned' materials might be assessed against this criterion, allowing for the integrated outcomes approach of strategic design (Hill and Melander 2025). Yet whilst the relationship between bio-based materials and health is likely to be particularly fruitful area of research, reinforcing 'planet-aligned' choices, the Circle framework's emphasis is at least initially on the environmental impact of materials flows.

CRITERIA

Employment and economy

As noted, productivity in construction is only relevant if pursued in the direction of 'planet-aligned' material outcomes. A narrower idea of productivity improvement holds a particular allure for policymakers nonetheless (Hill 2025), not least as the built environment sector suffers in comparison to others (Klein and Thompson 2024). Circle's framework incorporates efficiency within the industry-aligned criteria of scale, time, and cost. However, we must recognise that productivity increases ('more output for less input'), might also lead to a reduction, or at least displacement, of local employment in Australia.

Yet as the work of Material Cultures (2022) makes clear, construction-related activities involving locally-sourced biomaterials may be healthier and more rewarding work than than current industry's typical employment roles. The 'slowness' of these bio-based processes, defined around seasonality and long-running, culturally-meaningful local craft traditions, may become a virtue rather than a drawback, not least as local/bioregional employment practices could be an increasingly important counterpoint to an age of mass automation. Material Culture's various research projects—e.g., *Growing Place* (2025a); *Building Skills* (2025b); *Wetlands and Construction* (2023)—indicate the potential for a reconfiguration of the sector around a richer sense of value and values. An extended criterion could include: *'the extent to which this material creates healthy, meaningful, and valued local employment'*. Note that this could does not preclude the use of robotics and fabrication technologies; just that their use must be assessed in a broader 'planet-aligned' context, rather that mere speed and cost. This aspect could be extended further beyond employment, based on a material's ability to produce local, resilient economies, organised around bioregional capacity and diversified manufacturing technologies.

CRITERIA

Participation and self-build

The possibility of a different form of built environment sector—oriented around retrofit on the one hand, and on locally-sourced bio-based materials on the other—allows for a greater diversity of design and construction approaches. For instance, self-build systems by Japan's VUILD or the global Wikihouse movement prioritise locally-sourced bio-based materials, constructed directly by communities, with exemplary build quality. Self-build aligns with the idea of 'smaller architecture' (Meredith 2025), which recognises long-term shifts in demographics, which suggest reduced demand for new housing in most countries, as well as working practices suggesting similar for commercial property (Dorling 2020).

This reduction in scale maps onto the reality of material budgets. The architects we spoke with also described the potential of building smaller i.e., the EcoCocon straw cassette system at four-storeys is insulation and load-bearing structure in one, whereas, for example, the Hyllie buildings's 12-storeys require an additional mass timber core. Lendlease's in-house sustainability teams noted that truly addressing embodied emissions may be largely incompatible with very tall buildings. WeCanMake's MultiMax modular building system (2025), designed by Waugh Thistleton, allows for locally-sourced bio-based four-storey buildings to be built by communities.

Overall, the possibility of 'planet-aligned' bio-based materials aligns well with advanced self-build systems, which can now take advantage of digital design, modular fabrication, as well as locally-sourced materials and labour, particularly by the users of such buildings. Accordingly, the Circle framework could be extended to incorporate *'the extent to which the material affords locally participative forms of construction'*.

CRITERIA

Aesthetics and culture

Our discussions with architects repeatedly noted that the positive aesthetic and cultural values of biomaterials. Our respondents suggested that there was no particular issue with using straw cassettes or hemp blocks versus other typical forms of modular construction, but that there are interesting new material and spatial qualities to explore. Most respondents noted that the aesthetic, and more broadly expressive and relational possibilities of biomaterials offer great promise.

As Petersen (2025) notes, a material turn suggests highly engaged, expressive, and diverse forms of architectural practice, and a richer care-based cultural relationship with materiality, for both designers and users of buildings. After a century of architectural culture valorising the materials of the *'Great Acceleration'* (McNeil and Engelke 2014), in which the dynamic of *'form follows fuel'* (Urban and Calder 2025) has led to the unthinking lock-in around the 'industry-aligned' materials indicated here, this will require new architectural movements, which help produce desire for an alternative 'planet-aligned' material future.

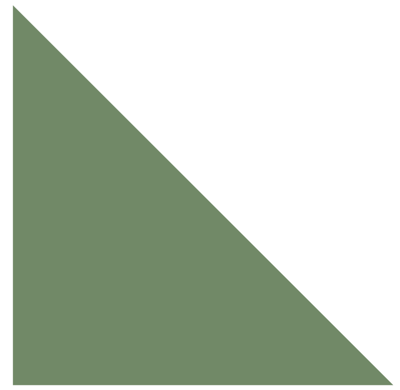
> We long to live in communion with nature. We find both comfort and beauty in a passing breeze, shifting light, the shade of a hot day, or sunlight streaming in on a cold morning. Parts of a building made from earth or timber age with time, gaining depth and character... Nature is changeable, sometimes severe, often delicate. And it is precisely this quality that invites human affection and a desire to care for and sustain it over time ... Architecture that connects with nature is a new concept for reorienting the technologies of modern architecture in exactly this way.
> Nori Kawashima (2025)

Although any semblance of a quantified metric would be precisely the wrong approach to assess the more complex fields of cultural production, Circle's framework could be extended to note the potential of a material choice to create new, design-led aesthetic and cultural movements. Making the framework tangible through prototyping—through building—would immediately foreground this aspect of a material return in architecture and construction.

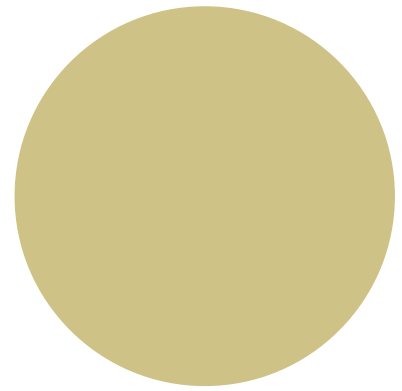
> Architecture needs a revolution as spectacular and all-changing as the advent of fossil-fuel architecture, and this is only at its very earliest stages. To stimulate an appetite for change amongst a wider public, architects need to make a zero-carbon future achingly attractive, not just threaten people with apocalypse if we keep going like this. There is an urgent need for the Le Corbusiers and the Lina Bo Bardis to emerge, producing charismatic architecture that meets the needs of our latest energy revolution, showing us a better life awaiting us once we escape the destructive pursuit of more, newer, bigger stuff. We need a worldwide diversity of new-old ideas and images made compelling and irresistible by the brilliance of architectural design.
> Florian Urban and Barnabas Calder (2025)

Cedric Price asserted that the *"whole nature of architecture"* is that *"it must create new appetites, new hungers"* (quoted in Obrist 2003). We need architectural design, alongside other disciplines, to help create an appetite for the *"better life"* that Urban and Calder call for, rather than simply trailing after the fuels of the previous age.

A strategic portfolio



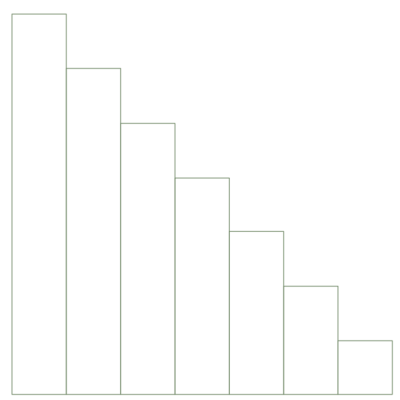
Roadmap



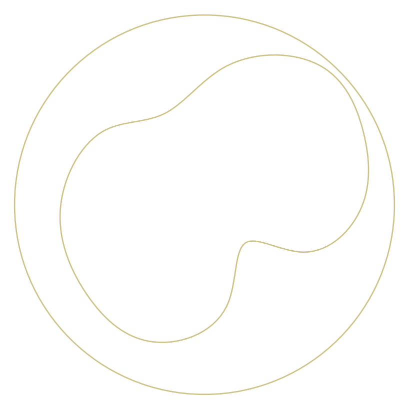
Palette

Plan

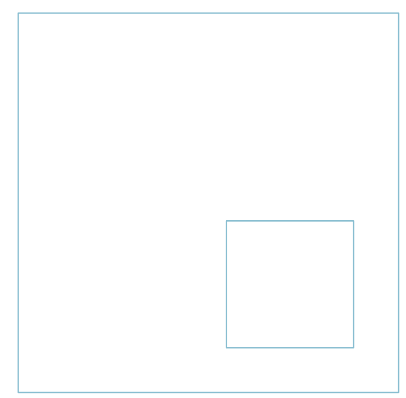
Following the mission-oriented innovation approach (Mazzucato 2021; Hill 2022), with its emphasis on a strategic portfolio addressing systemic challenges, *Circle* follows the *Reduction Roadmap*. The Roadmap's task is to describe the material budget for an Australian built environment sector that works within planetary boundaries—a necessarily 'sufficiency'-oriented agenda. Circle's role is to *expand* possibility, by indicating the material palette that could produce a thriving, regenerative environment within those parameters, offering designers, builders, developers, and communities an alternative diversity of bio-based possible futures to build and to grow. As mission-oriented innovation attempts to move quickly from strategy and engagement to prototypes and systems demonstrators, the first phase of Circle sketches concept designs for three prototypes, each conveying different ways of realising a circular built environment, building on the material analysis. This interplay suggests a third element: a reinvention of building regulation, policy, and practice in Australia, allied to new spatial plans, industrial strategies, and economic models. For example, a plan for *Australian housing within planetary boundaries* would be a natural next step.



Australian Reduction Roadmap v1
(2024)



Circle framework v1
(2025)



Housing Plan B
(2026)

Circle / Part 2 / Planet-aligned materials

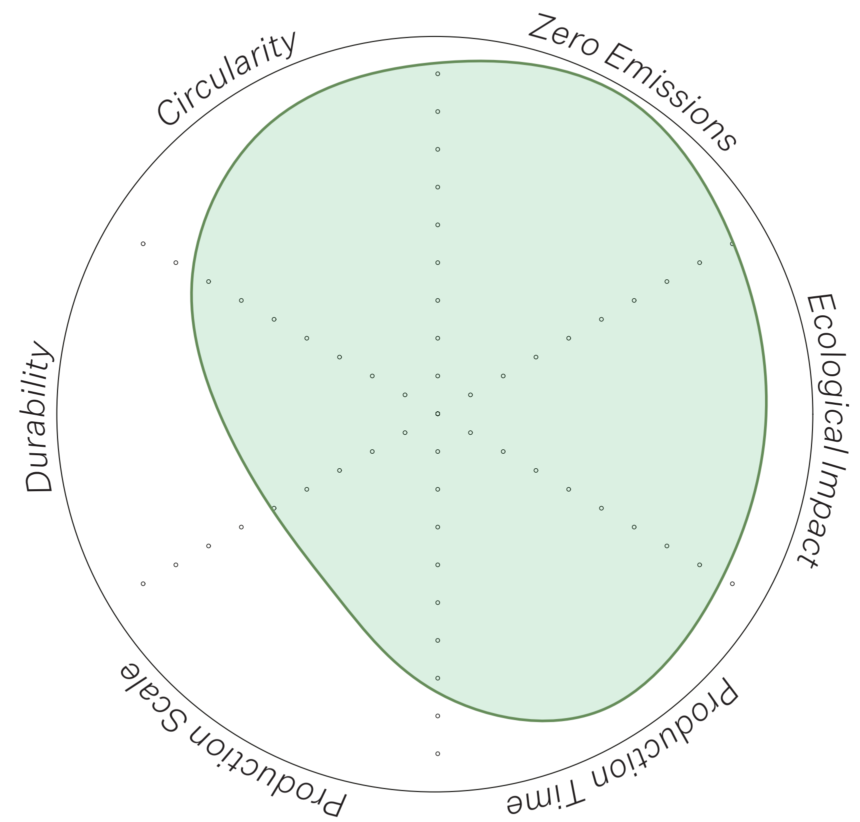
Hemp
Straw
Timber
Stone
Earth

Woodleigh School Futures Studio, Langwarrin McIldowie Partners (2025)

School building in Victoria designed by McIldowie Partners in association with Joost Bakker, and with Frank Burridge as Project Architect. The building features a wicking bed green roof, with a pergola of reclaimed timber from St. Kilda Pier Wharf. Interior features first 100% Australian grown hemp kitchen, sliding hemp panels to partition each room, and hemp desks with a plant-based bio-resin epoxy finish. Interior ceilings and walls are strawboard panels.Glazing unit framing is made with low emissions aluminium using a high percentage of recycled aluminium. The building sits on a ‘lower-embodied carbon’ concrete slab.

HEMP

Hemp

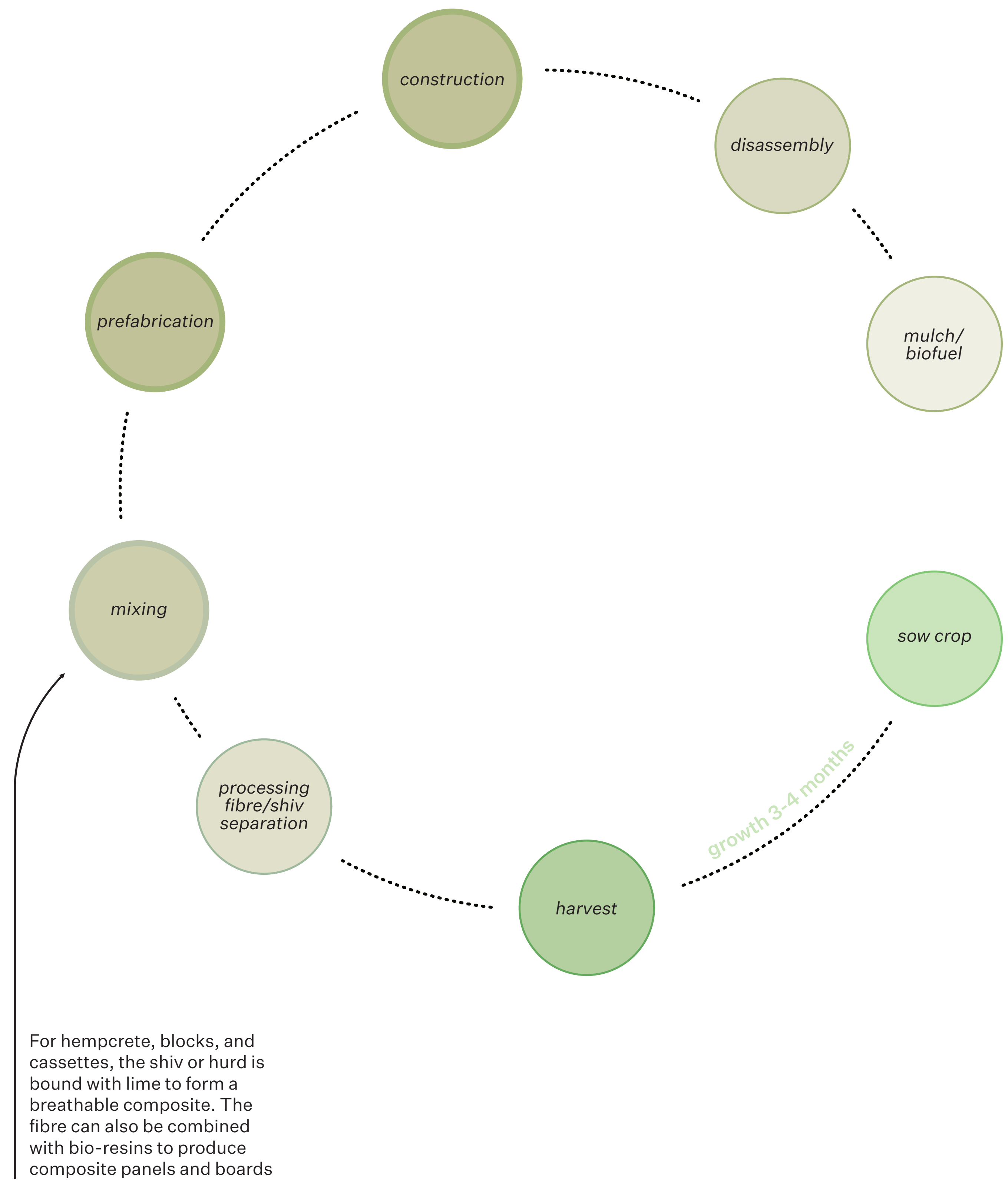


HEMP offers one of the more promising pathways into circular building systems. However, its potential in Australia remains largely speculative rather than realised. As a fast-growing annual crop, hemp sequesters carbon rapidly and can be returned to the biosphere at the end of its life, forming part of a regenerative material cycle, and Australia's climate is broadly suitable for hemp cultivation, particularly across temperate and subtropical regions. Yet adoption in construction relies on the presence of processing infrastructure and market readiness.

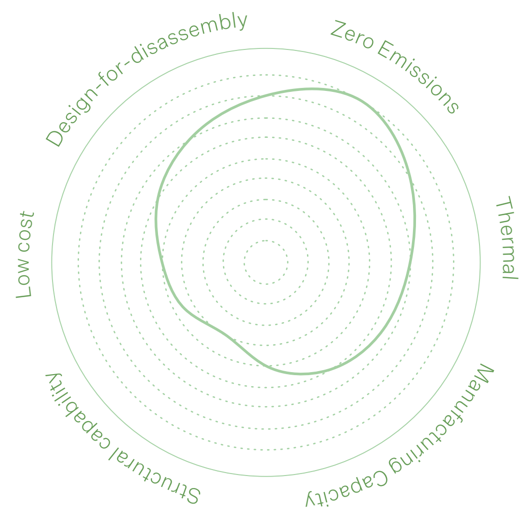
While small-scale production exists, the absence of large, decentralised decortication facilities—which separate the hurd used in hempcrete and composite panels from the fibre— remains a significant barrier. Significant investment is required to establish these systems before hemp can become a mainstream construction feedstock. This lack of industrial strategy currently manifests itself in an unnecessarily high cost for what could be a highly affordable material. At present, hemp is used directly in lime-based hempcrete and timber–hemp composites, but applications such as hemp fibreboard or façade cladding lack reliable supply chains and commercially proven non-synthetic binders. Research into natural resins and mineral or bio-based adhesives continues, but has yet to reach viable scale for industrial production.

Still, hemp has exceptional ecological potential nonetheless. Farmers appreciate its ability to serve as a rotation crop, improving soil health while producing a wide range of outputs, oils, textiles, paper and fibres, of which building materials are only one application. Its capacity to sequester carbon at a higher rate than most conventional crops underpins strong lifecycle performance. The challenge lies in expanding its processing and manufacturing capacity alongside standards and industry confidence. Therefore, hemp sits at the threshold between possibility and practice, illustrating how bio-based materials depend not only on climatic viability but also on the infrastructure and systems that enable their use.

Typical hemp production cycle

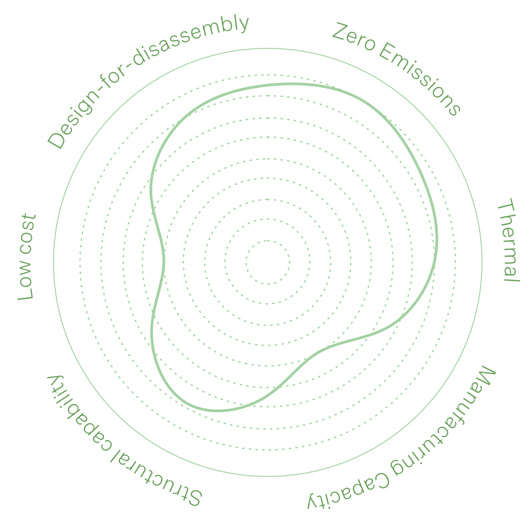


Hempcrete



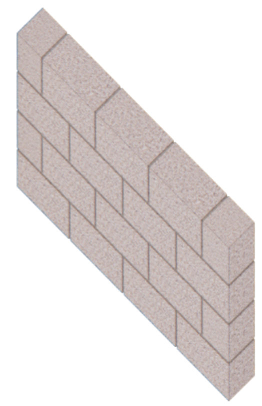
HEMPCRETE is a mix of hemp shiv, lime, and water, producing a mineralised, lightweight walling material that is both insulating and vapour-permeable. It is used as infill within timber framing, where it provides thermal mass, acoustic buffering, and humidity regulation. The material requires formwork and careful tamping during placement, making construction comparatively labour-intensive. Once cured, hempcrete forms a continuous wall that allows moisture to move through it, helping to regulate humidity and reduce condensation. Its physical properties suit a wide range of Australian climates, particularly where cooling, shading, and cross-ventilation are prioritised. While not structural, hempcrete replaces multiple layers of conventional insulation and lining, combining insulation, thermal mass, and breathability in a single construction layer.

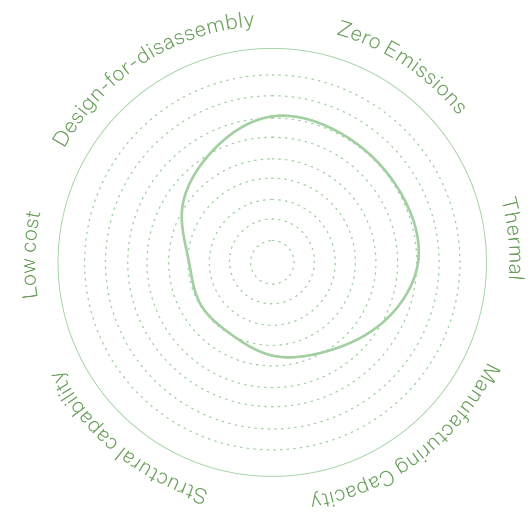
Hemp cassettes



HEMP CASSETTES are prefabricated wall or roof panels combining hemp-based insulation, typically hemp shiv or fibre, with a timber frame and breathable linings. Produced off-site, they enable precise fabrication and rapid installation, reducing on-site labour and improving quality control. The hemp mix is compacted within formwork, providing consistent density, insulation, and moisture regulation. The cassette system can act as the primary structure, suitable for mid-rise construction of up to five or six storeys. Once installed, the panels form a vapour-permeable enclosure with high thermal and acoustic performance. Broader implementation in Australia remains limited by the small scale of hemp cultivation and the absence of established fibre processing, prefabrication capacity, and consistent material supply chains material supply chains.

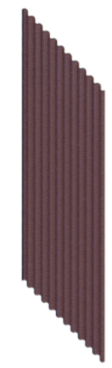
Hemp blocks

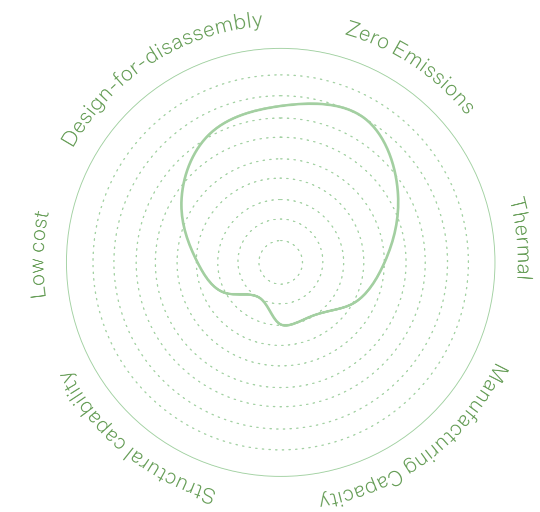




HEMP BLOCKS are modular units made from compressed hemp shiv and a lime-based binder, forming breathable, insulating components for wall construction. They are typically used for non-load-bearing infill or partition walls, assembled with thin lime mortar joints or dry-stacked systems. The blocks provide thermal inertia, humidity buffering, and acoustic separation, contributing to stable and comfortable interiors. Their consistent size and ease of handling support straightforward on-site assembly with minimal waste. Hemp blocks have a wide range of applications across different building types, providing an alternative to conventional concrete or masonry systems.

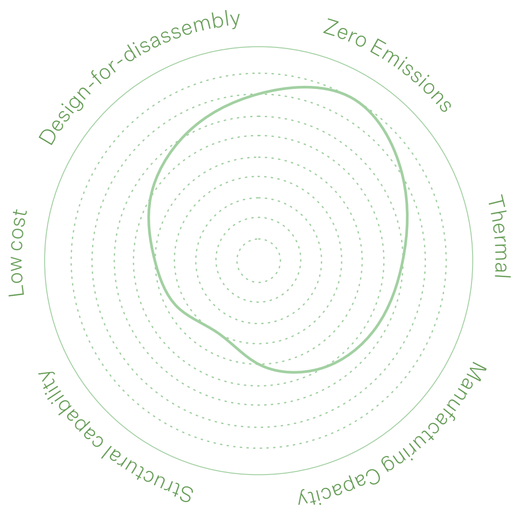
Hemp fibre panels





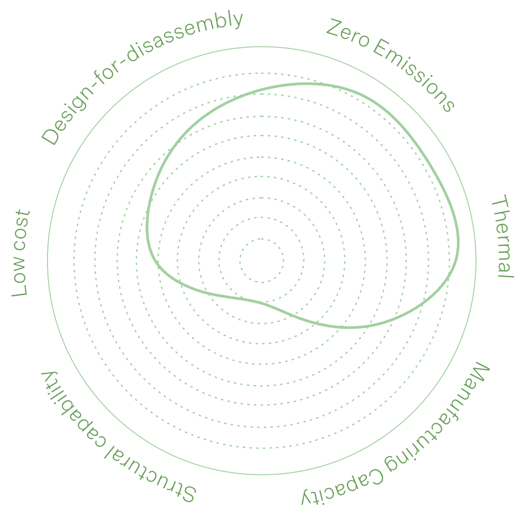
HEMP FIBRE PANEL is a sheet material made from the long bast fibres of the hemp plant, bound with a bio-resin matrix to form a dense, weather-resistant composite. The fibres are layered and heat-pressed to create rigid panels suitable for cladding and roofing, a category where few bio-based materials can perform effectively. The boards combine good tensile strength with moisture resistance, and a fine textured finish that can be left exposed or treated with natural oils. Derived from agricultural by-products, the material offers a durable and low-toxicity alternative to metal or cement-based panels. Despite its promise, manufacturing capacity tends to be extremely limited, with relatively few producers constraining broader application and supply.

Hemp fibre board

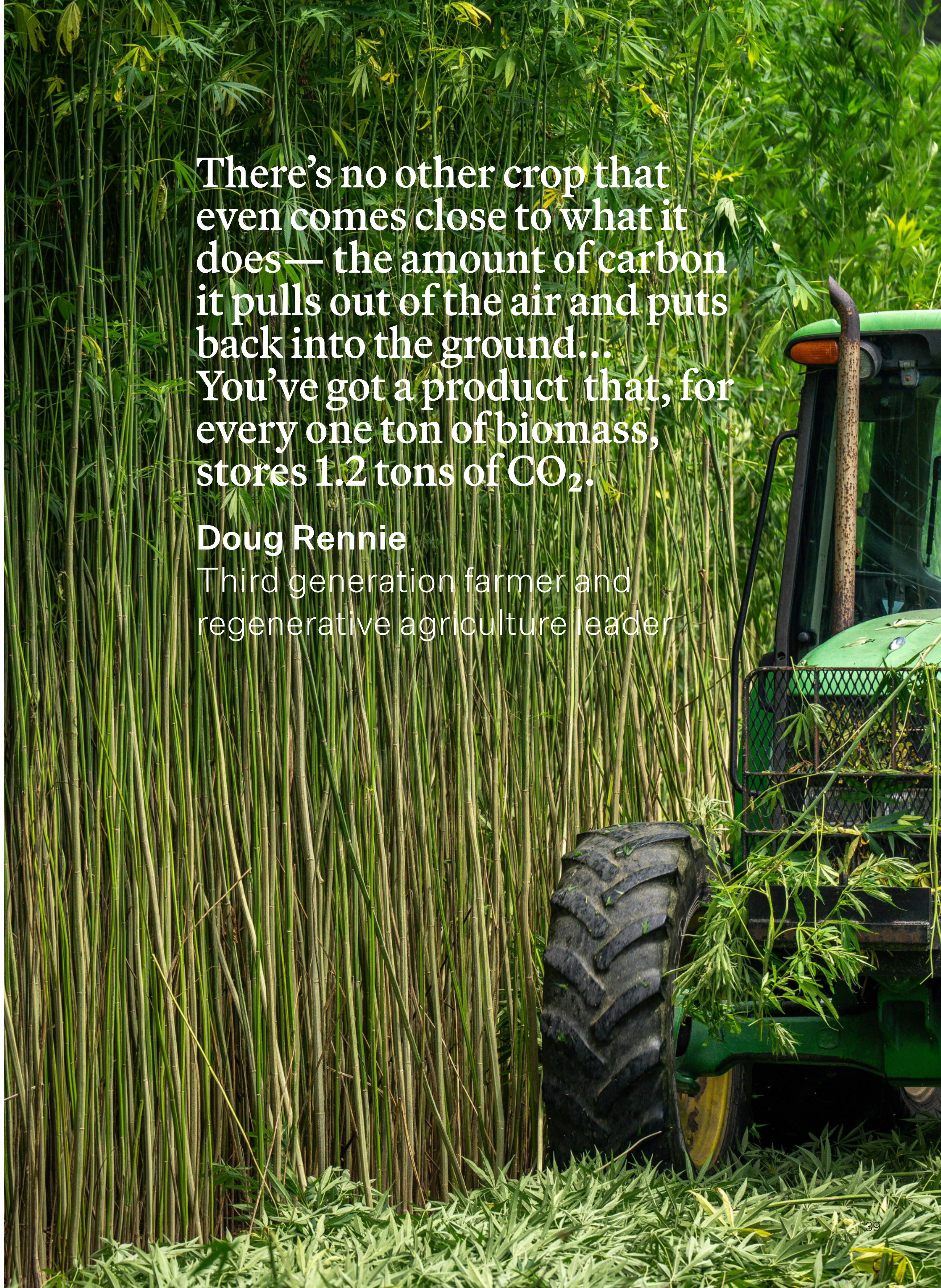


HEMP FIBRE BOARD is a pressed interior panel made from hemp bast fibres bonded with bio-based or low-emission resins, providing a renewable alternative to MDF, OSB, and particleboard for linings, joinery, cabinetry, and furniture. Panels are easy to machine, with good screw-holding capacity and a surface that accepts oils, waxes, paints, and laminates. Moisture response is comparable to other wood composites; edge sealing is recommended, and the material is not intended for exterior use. Mechanical fixing allows for straightforward assembly and potential disassembly. Supply in Australia is currently limited, with most products imported or produced in small batches. A key technical challenge remains developing commercially viable, compostable bio-based binders, as many current systems still depend on hybrid or partially synthetic resins.

Hemp insulation



HEMP INSULATION is made from processed hemp fibres formed into batts, rolls, or mats. Many batt products use a small proportion of binder fibre to hold shape (commonly polyester, but some versions use PLA/cornstarch-based binder fibres instead). It provides strong thermal and acoustic performance, remains vapour-permeable, and is generally low-toxicity and safe to handle. In Australia, supply is still limited, but compared conventional synthetic batts, hemp-based insulation is a renewable, lower-impact option.



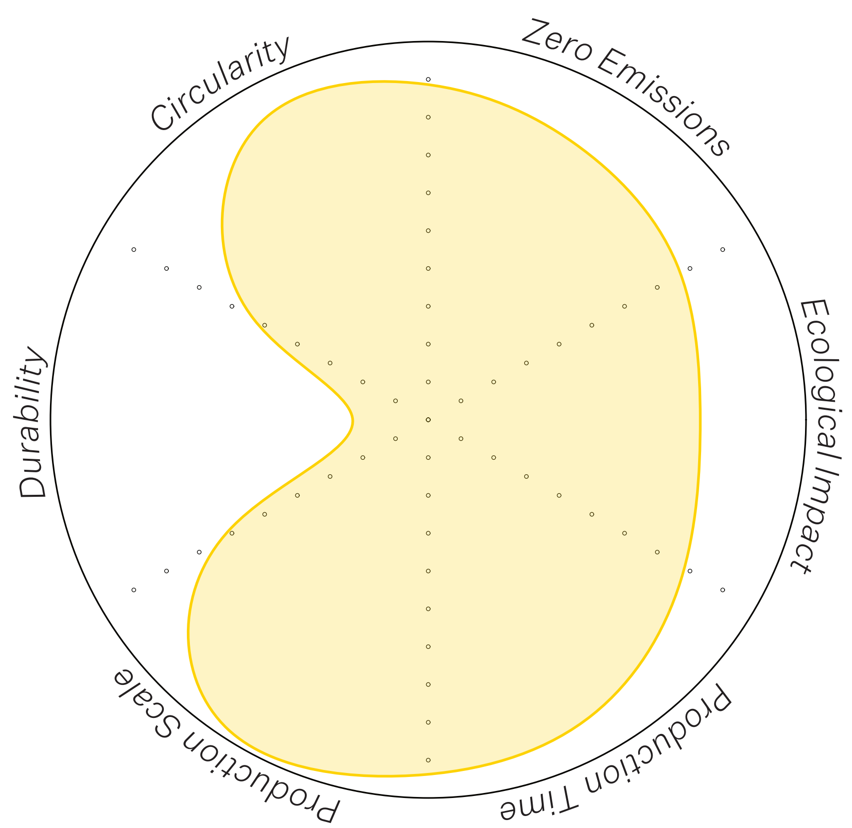
There's no other crop that even comes close to what it does— the amount of carbon it pulls out of the air and puts back into the ground... You've got a product that, for every one ton of biomass, stores 1.2 tons of CO_2.

Doug Rennie
Third generation farmer and regenerative agriculture leader

Powerhouse Place, Mildura Public Realm Lab (2023)
Three new buildings at Powerhouse Place in Mildura, Victoria, designed by Public Realm Lab, are the first public hemp masonry buildings in Australia. The hemp was sourced from Victoria, indicating the possibility of linking architecture to agriculture, with new skills and supply chains.

STRAW

Straw



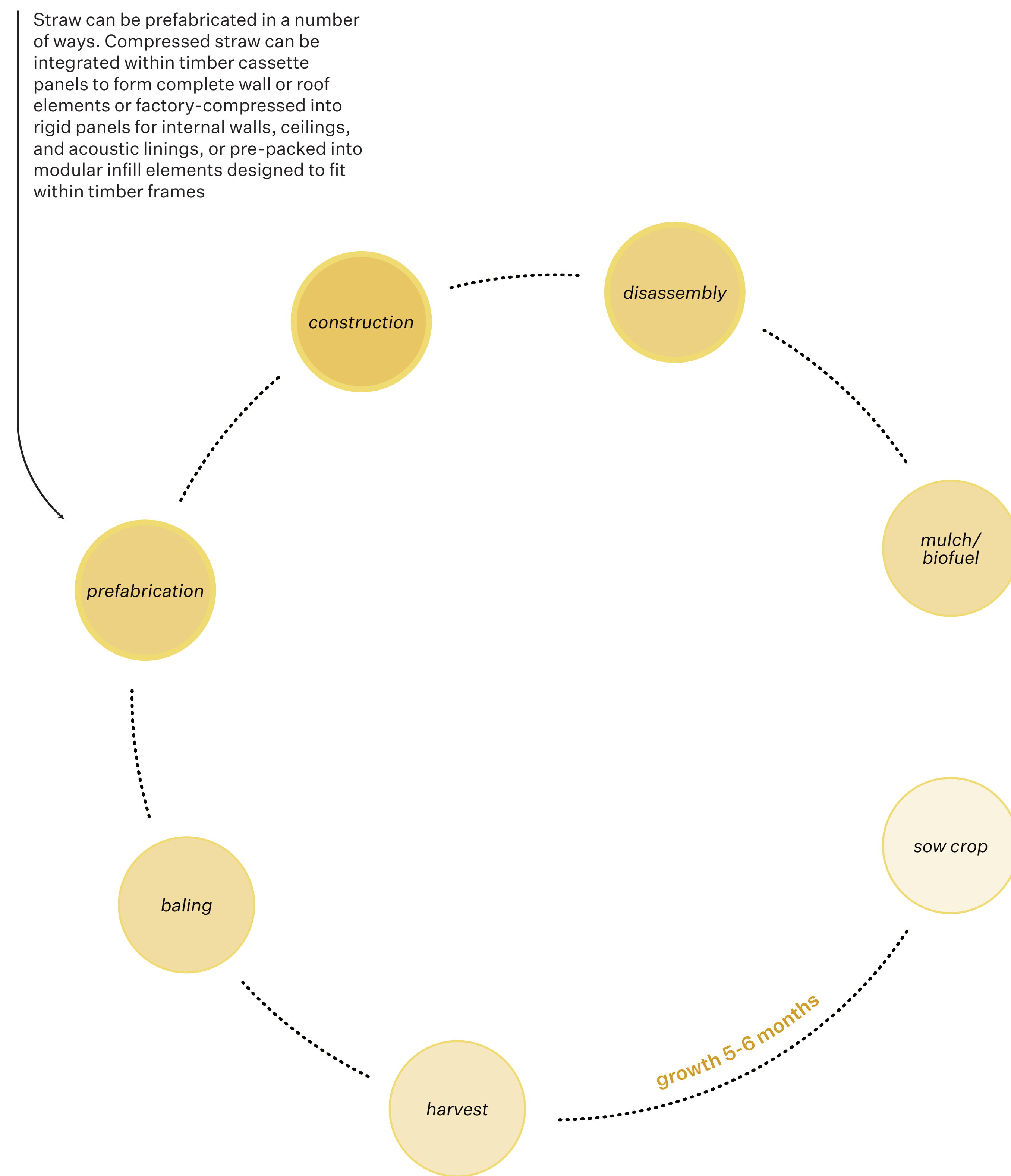
STRAW is an abundant agricultural by-product in Australia, giving it a high production scale and immediate availability for construction uses. It can be integrated into building materials without competing with food production, and when managed under regenerative farming systems its ecological impact can be relatively low. However, the broader footprint is shaped by prevailing agricultural practices, stubble burning, petrochemical fertilisers, and soil depletion all influence outcomes, and large-scale Australian cropping systems still have considerable room to improve. The value of straw lies in its volume and renewability, where even a small fraction of annual production could support a wide range of building applications.

Straw is used in several building systems. Straw infill employs loose or lightly bound straw within timber framing, providing insulation, mass, and breathability. Straw cassettes are prefabricated wall or roof panels combining compressed straw with timber framing, allowing faster installation and consistent performance; with suitable framing, they can act as the primary shell for mid-rise buildings. As with hemp, lack of fabrication infrastructure in Australia currently results in unnecessarily high costs for what otherwise would be highly viable and low cost building elements.

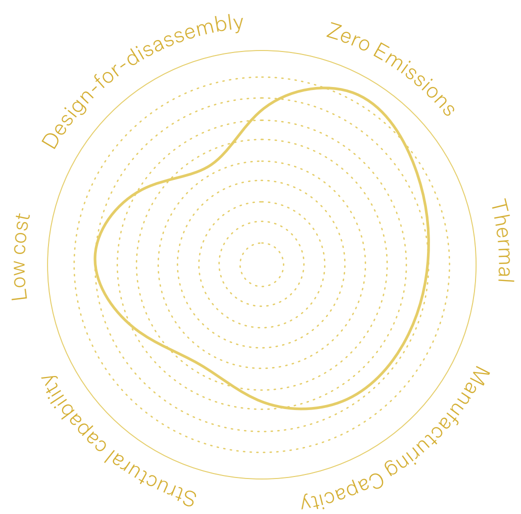
Compressed straw panels are dense boards made under heat and pressure, offering acoustic performance, and fire resistance for interior linings and partitions. Straw bales are used in small-scale, non-load bearing construction, typically within timber frames or rendered directly with clay- or lime-based plasters. Thatching, once made from long-stem heritage cereal varieties, demonstrates the historic durability of thatched roofing, though such crops are now rare, having been replaced by shorter-yielding modern varieties.

Straw has one of the most established supply chains of any bio-based materials in Australia and provides a scalable, low-toxicity material for interior panels and wall systems.

Typical straw production cycle

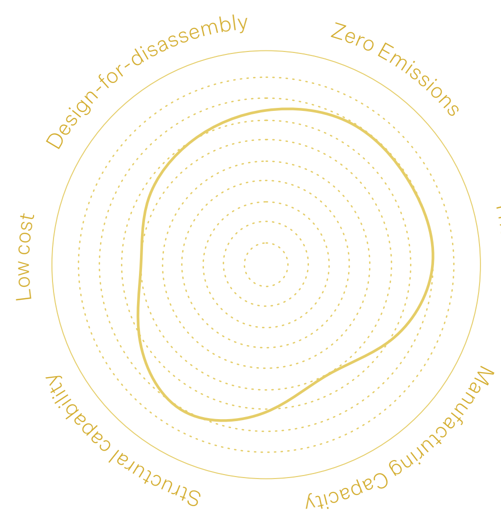


Straw infill



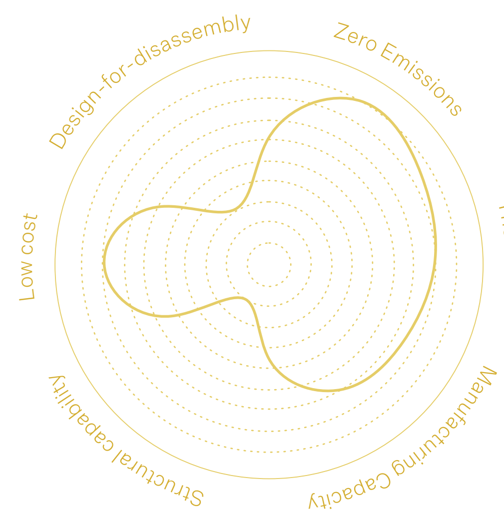
STRAW INFILL uses loose or lightly-bound straw placed between timber framing to create a breathable, insulating wall layer. Installed at moderate density, the material provides thermal mass, acoustic absorption, and effective humidity buffering due to its natural vapour permeability. When paired with external weather protection, typically timber cladding or a clay or lime render, straw infill forms a stable, durable wall system. As a non-structural system, it depends on timber framing for load-bearing capacity, but replaces multiple synthetic layers of insulation and lining with a single natural material. Straw infill makes productive use of agricultural by-products already available at scale, offering a simple construction system for small scale dwellings.

Straw cassettes



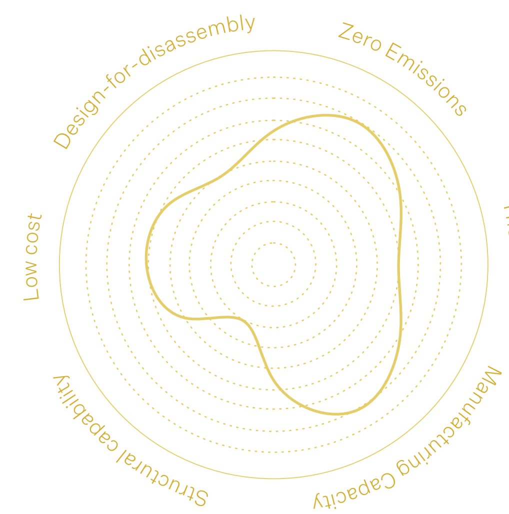
STRAW CASSETTES are prefabricated load bearing wall and roof panels that combine densely packed straw with timber framing. The straw core provides high thermal and acoustic performance, while the timber members deliver structural capacity and fixing points for linings, membranes, and external claddings. The cassettes can act as the primary structural wall system for mid-rise buildings (typically up to ~6 storeys). Prefabrication reduces on-site labour, waste, and build time, offering a scalable pathway for bio-based construction.

Straw bale



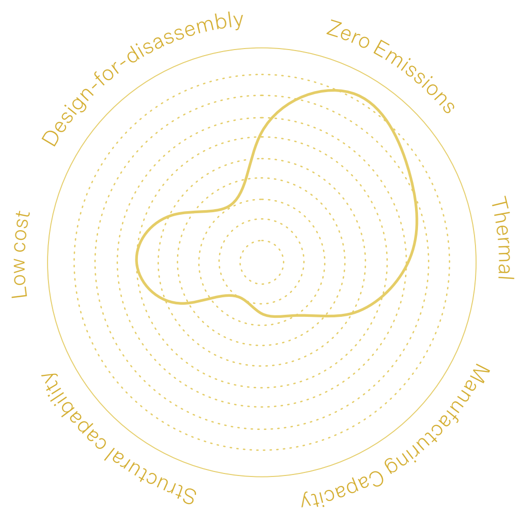
STRAW BALE construction uses densely compacted bales as a non-structural infill within timber framing or, in some cases, as self-supporting wall elements protected by thick clay or lime renders. The bales provide excellent thermal resistance, sound absorption, and humidity buffering, forming a breathable envelope. When rendered, bale walls create a continuous, monolithic surface with substantial thermal mass and strong indoor environmental performance. While best suited to small-scale buildings, straw bale construction remains one of the most accessible and low-impact ways of using agricultural by-products in building.

Straw compressed panels



STRAW COMPRESSED PANELS are rigid, non-structural boards made by hot-pressing agricultural straw fibres between heavy paper facings, producing dense sheets without synthetic binders. The process fuses the fibres through heat and pressure to create a durable, impact-resistant core suitable for interior wall linings, ceilings, and acoustic partitions. Panels are typically installed using proprietary framing and mounting systems designed to accommodate their weight, rigidity, and acoustic performance. Although straw is a combustible feedstock, the high density and low oxygen content of panels mean they tend to char rather than ignite rapidly, and they have been fire-tested and certified for compliant interior lining applications.

Thatching



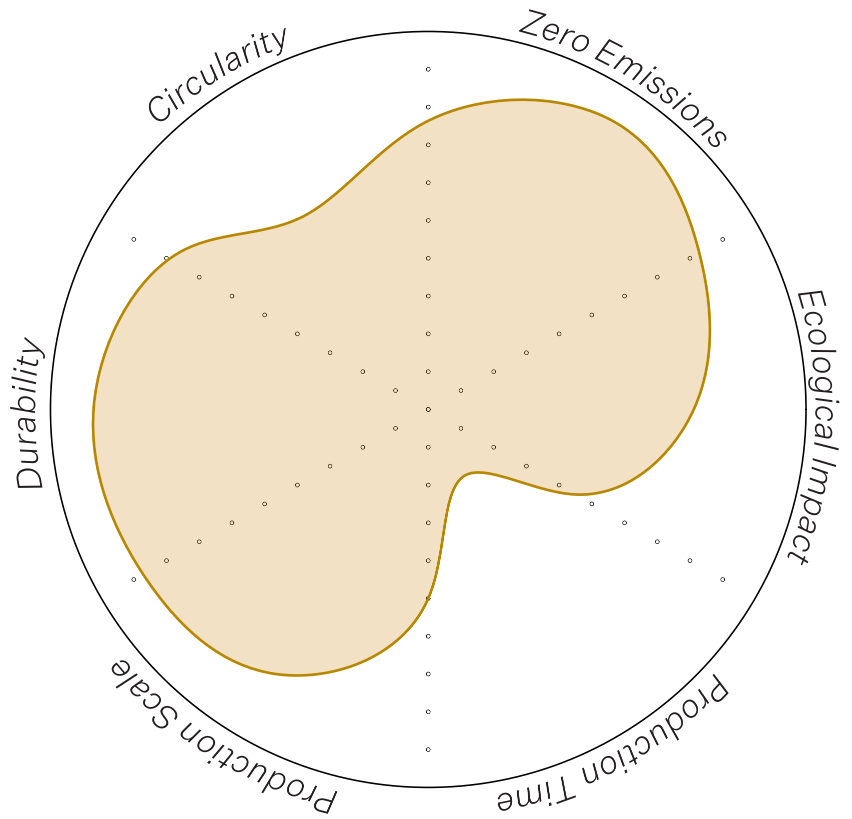
THATCHING fuses bundles of plant fibres to form an insulating, breathable, and weather-resistant roofing or cladding system. Traditionally, long-stem cereal varieties provided the best material but modern wheat crops in Australia are predominantly dwarf cultivars, producing stems too short for high-quality thatching. Globally, water reed is considered the ideal thatching crop, yet it is not commonly grown locally. Kangaroo grass, an Australian native alternative, can be integrated into regenerative farming systems and offers suitable length and durability for thatching. When installed by skilled craftspeople, thatching can last several decades and is maintained through partial repair rather than full replacement.

Sundby School, Sundby Henning Larsen (2026)
Building features thatched façade, derived from traditional local construction techniques, expected to last 80 to 100 years. Agricultural waste like wheat straw sequesters carbon five-to-ten times more effectively than wood.

Hyllie building, Malmö Kaminsky Arkitektur (2026)
Mixed-tenure housing, with shop and café on ground floor. Designed by Kaminsky Arkitektur, and featuring EcoCocon straw panels, with a glulam timber core and timber cladding. Interiors feature clay boards rather than gypsum boards, and low-emissions wood-based boards in bathrooms and kitchens over typical higher-emission alternatives. Some concrete is for the foundations, but with basalt stone-based rebar replacing steel, and not at all used in the stairwell or elevator duct. Pictured during construction, December 2025.

The Plus for Vestre AS (2022)
BIG Architects

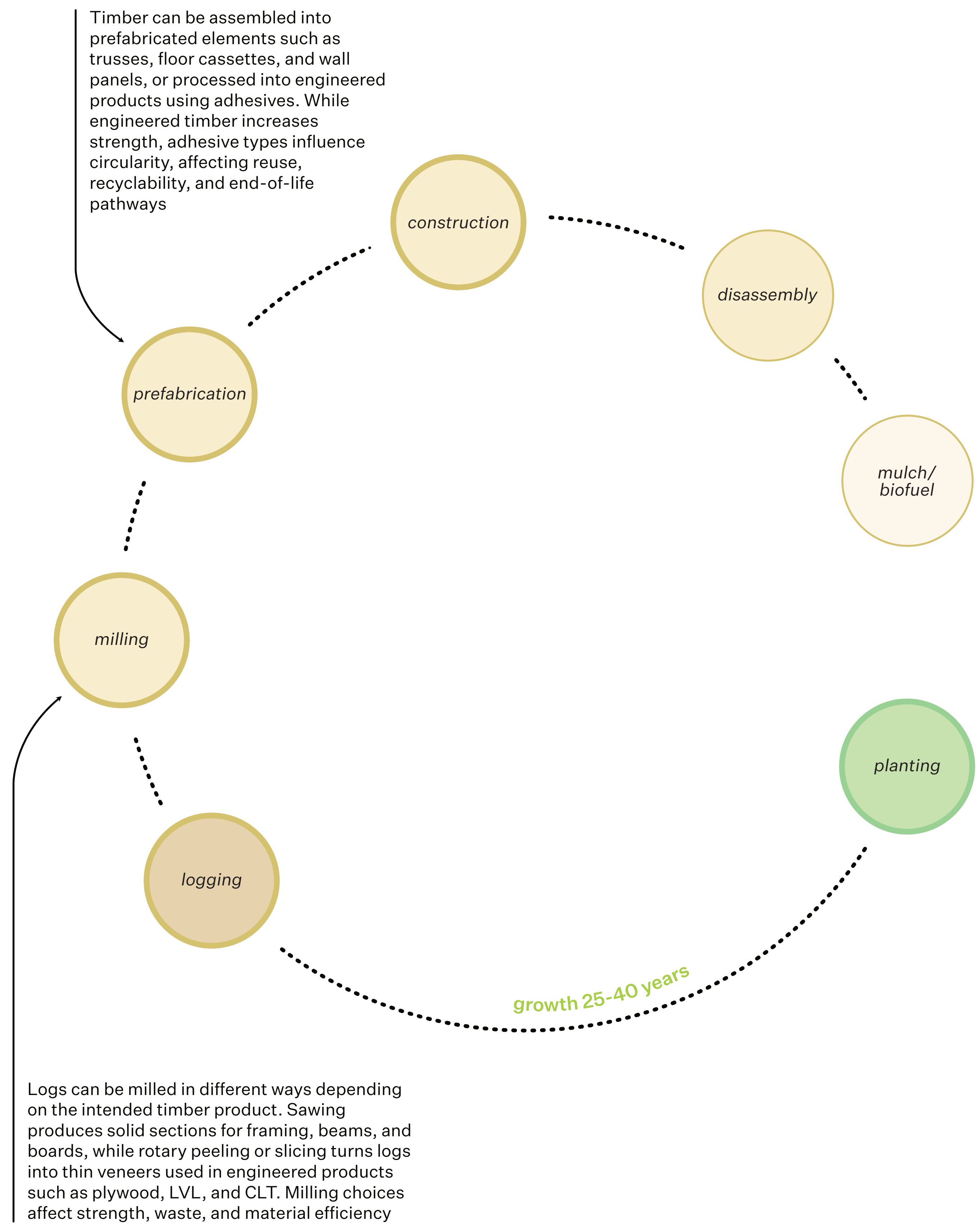
Timber



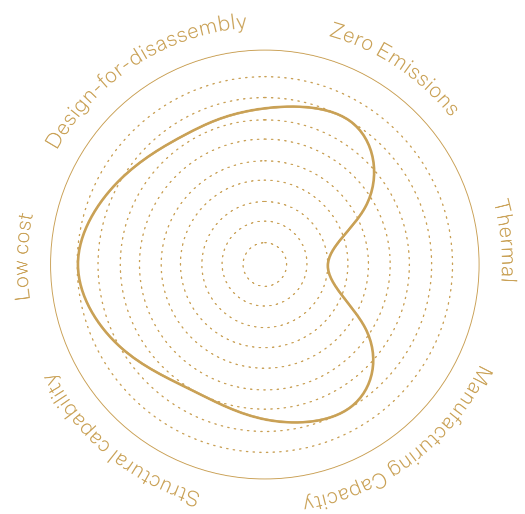
TIMBER is one of the most critical materials for a future circular construction industry, offering structural capacity, biogenic carbon storage, health and aesthetic value, and compatibility with a wide range of building systems. When sourced from well-managed forests, it provides a flexible renewable alternative to emissions-intensive materials. Yet Australia's forestry landscape presents significant constraints. Much of the nation's plantation estate is dedicated to pulp or softwood rather than structural hardwoods, investment in regenerative forestry and sustainable production infrastructure has been uneven, and logging of native and old-growth forests continues to undermine ecological and social outcomes. Bushfires present particular local issues. Growth cycles are slow, requiring decades to replenish, and forestry practices strongly influence biodiversity, soil health, and water systems. These challenges mean that while timber is vital, it cannot be the sole answer to decarbonising construction without substantial reforestation and reform of plantation, harvesting and production practices.

Timber is used across several building systems. Conventional light-frame construction relies on sawn softwood while mass timber systems, such as cross-laminated timber and glulam, provide larger spanning capability and enable mid-rise and commercial applications. Timber-fibre cassettes, combining wood framing with straw or hemp insulation, reduce total timber demand while improving thermal performance. Timber is also widely used in interior linings, flooring, windows, and joinery, where its durability and reparability support long service life and ease of maintenance. Reuse potential varies: large beams, mass timber panels, and glulam elements can be reclaimed with careful deconstruction, while small sections and treated products are more likely to be down-cycled or chipped. While timber is a well-established building material in Australia, its future scalability depends on expanding diverse regenerative plantations and investing in sustainable production infrastructure.

Typical timber production cycle

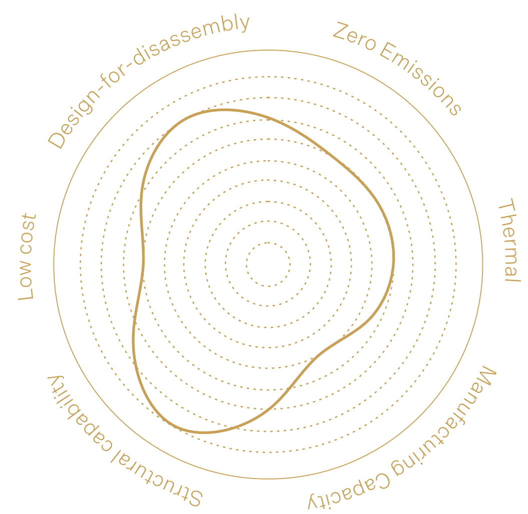


Sawn timber



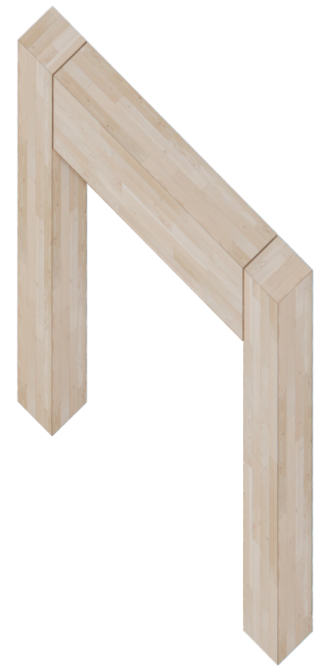
SAWN TIMBER is the simplest form of wood use, cut into studs, beams, joists, and rafters for structural framing. It provides reliable strength-to-weight performance and is easy to cut, fix, and modify on site, making it suitable for residential and light commercial construction. Properties vary with species, grading, moisture content, and treatment, and it requires protection against decay, termites, and prolonged moisture. Larger solid members can often be reclaimed or resized for reuse, while smaller sections are more commonly downcycled. With relatively low processing energy and established supply chains, sawn timber remains a practical structural material, though durability and availability depend on appropriate species selection and detailing.

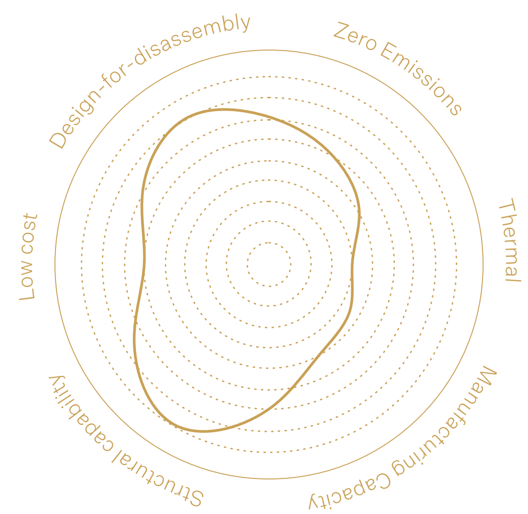
Cross laminated timber



CROSS-LAMINATED TIMBER (CLT) is formed from layers of timber boards glued at right angles to produce large, dimensionally stable panels for floors, walls, and roofs. The system enables rapid assembly, predictable spanning behaviour, and consistent performance in mid-rise or commercial timber buildings. Panel manufacture requires precision cutting, which can generate offcuts that are not always reusable, and the adhesive content limits biodegradability and recycling pathways. CLT performs well in fire due to its charring behaviour but still requires moisture protection and accurate junction detailing. It is best suited where panelisation, structural efficiency, or installation speed offer clear benefits compared to concrete or masonry systems.

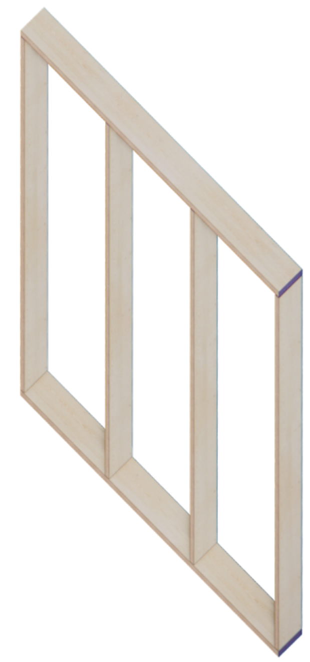
Glulam

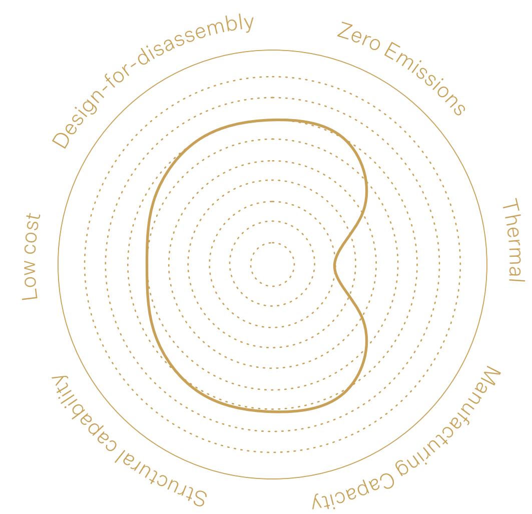




GLULAM consists of multiple timber laminations bonded in parallel to create beams and columns with high strength and stiffness. It can span long distances, form curved or straight members, and offers good dimensional stability for roof structures, portals, and expressive architectural elements. Performance depends on moisture protection and appropriate connection detailing, as glulam can be vulnerable to decay if left exposed. Adhesive use limits biodegradability and means recycling is difficult, though large members can often be reclaimed if connections allow clean removal. Glulam's strength-to-weight ratio and flexible geometry make it a practical alternative to steel in many applications, particularly where reduced structural weight or warmer architectural expression is desired.

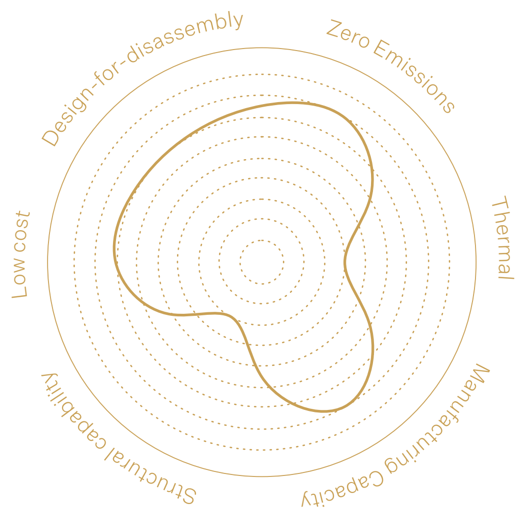
Laminated veneer lumber





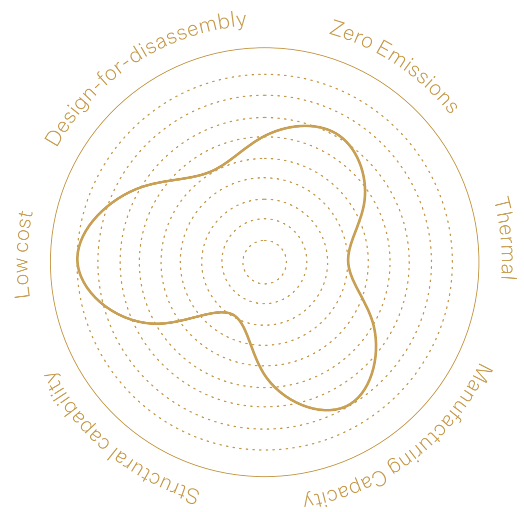
LAMINATED VENEER LUMBER (LVL) is manufactured from thin wood veneers bonded with the grain aligned, creating uniform, dimensionally stable members used for beams, lintels, joists, and portal frames. It offers predictable performance with fewer natural defects than solid timber and can achieve long spans with relatively low weight. LVL relies on structural adhesives that restrict biodegradability and complicate end-of-life processing, making reuse preferable where possible. Moisture protection is essential, as edge swelling can occur if left exposed. LVL is suited to applications requiring high strength, straightness, and consistent sizing, and it makes efficient use of small-diameter logs compared to traditional solid timber beams.

Timber Cladding and Flooring



TIMBER CLADDING AND FLOORING extends wood into interior surface finishes and external façades. These products use sawn boards, veneers, or profiled sections in a wide range of species and formats, offering lightweight, workable components suited to residential and commercial settings. Performance depends on species durability, protective coatings, and moisture detailing, particularly for external cladding where weather exposure and movement must be managed. While surfaces can be repaired or refinished, coatings, adhesives, and chemical treatments may limit recyclability or reuse. Timber flooring provides long service life when maintained, and internal linings offer good acoustic and thermal moderation. These applications make efficient use of smaller cuts and lower-grade timber. Research also suggests health benefits for inhabitants of timber-rich environments (Whyte et al 2025).

OSB Engineered Panels

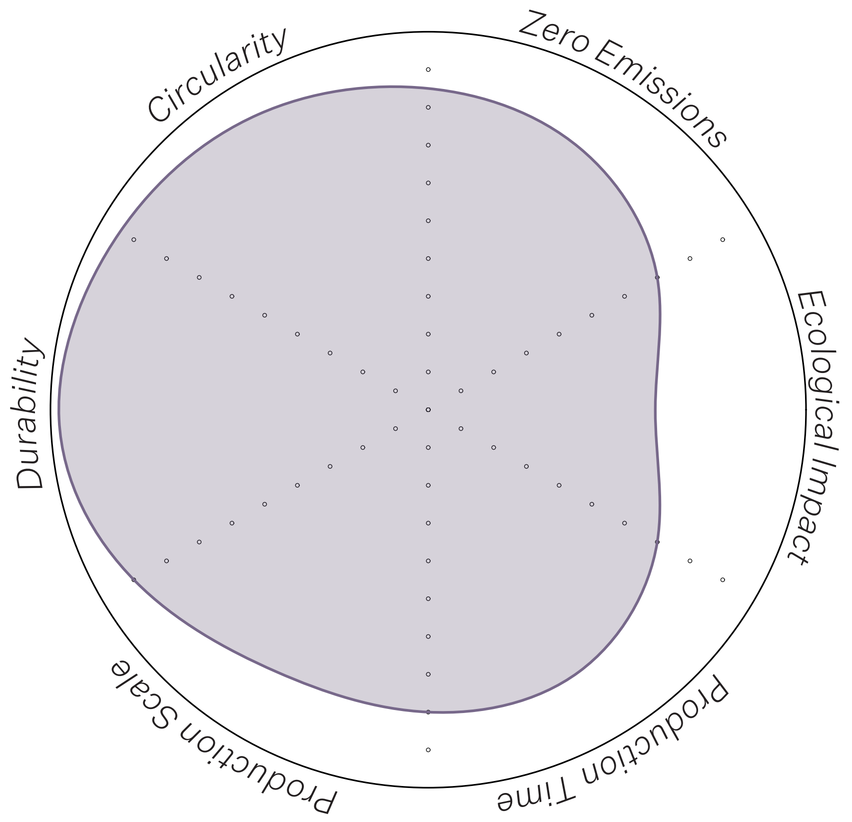


ORIENTED STRAND BOARD (OSB) ENGINEERED PANELS are produced from small wood strands mixed with synthetic resins and pressed into strong, versatile panels used for wall bracing, sheathing, and sub-flooring. It provides reliable structural performance and maximises resource efficiency by using small-diameter logs and fast-growing species. OSB is sensitive to prolonged moisture exposure, requiring careful detailing to avoid swelling or edge degradation. Many products contain formaldehyde-based adhesives, which can affect indoor air quality and limit recyclability, though lower-emissions resins are increasingly available. Reuse is possible if panels remain intact, but recycling options are limited.

Helsinki Central Library ALA Architects (2018)
The three-storey 17250 m² central library building for the City of Helsinki is a steel and concrete structure wrapped in a large-scale timber façade of Finnish spruce. Given the target lifetime of the building is 150 years, the timber required research by ALA Architects, Ramboll, and Aalto University's Aalto Wood, which led to new guidelines and standards for future wood construction in Finland, indicating how public procurement can drive innovation (Kaila and Heikkinen, 2020).


STONE

Stone



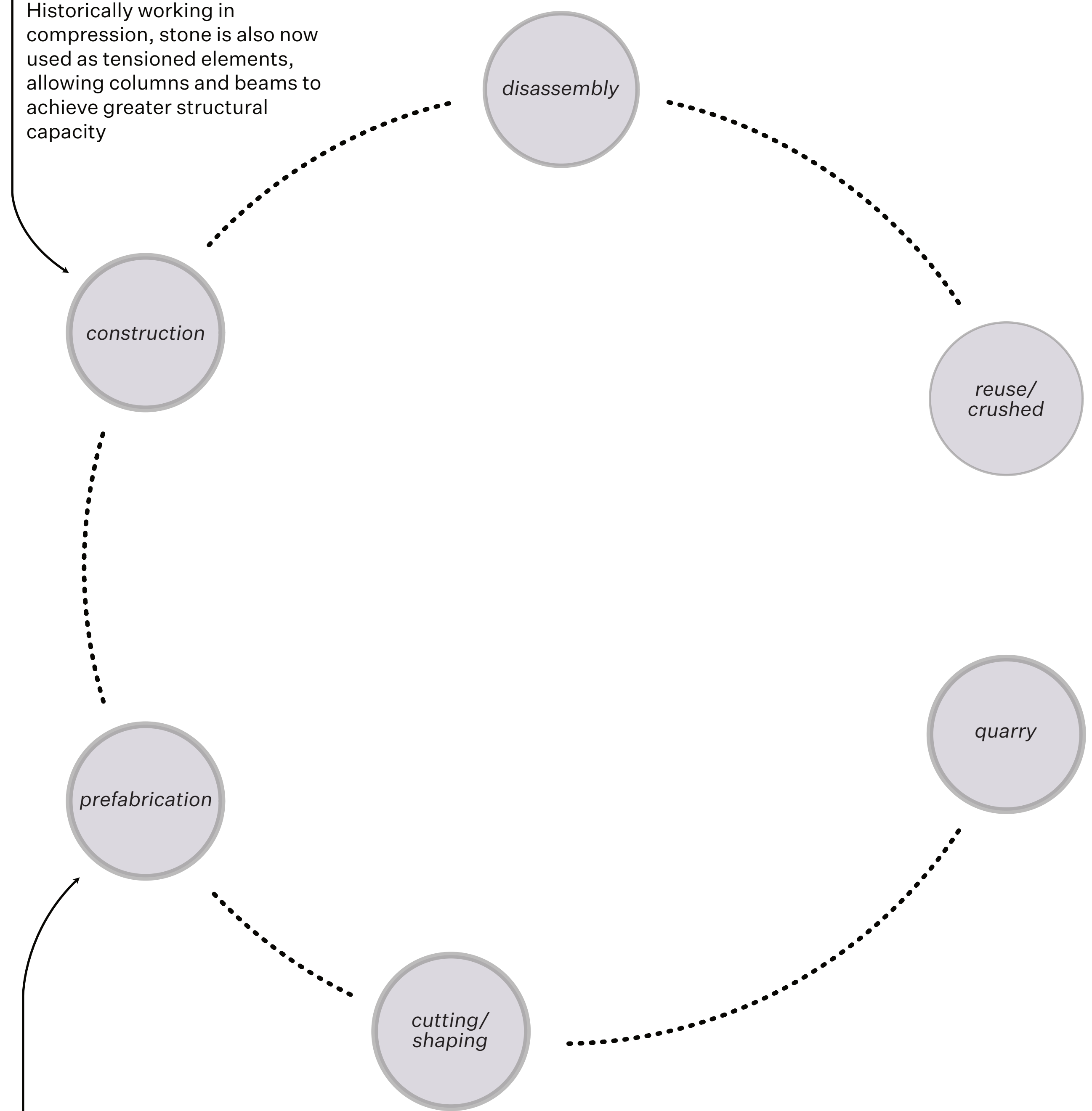
STONE is one of the most abundant construction materials available and requires minimal processing compared to cement-based products. It is used largely as extracted, involving cutting and shaping rather than chemical transformation, which keeps embodied emissions relatively low. Its broader environmental impact is shaped primarily by quarrying practices, which permanently alter landscapes and require careful site management, and by the transport required to move heavy stone long distances. Stone's value lies in its durability and longevity, with many historical buildings demonstrating service lives measured in centuries rather than decades.

Stone is used across several construction systems. Traditional load-bearing masonry employs cut blocks or ashlar courses, offering excellent compressive strength. Tensioned stone enables beams, lintels, and floor systems that can replace reinforced concrete in many applications. Thin stone cladding panels offer a durable exterior finish and can be fixed with mechanical systems that allow disassembly and reuse.

While stone relies on extractive processes and can present logistical challenges due to its weight, it has one of the highest circularity potentials of any material. If carried out carefully, quarrying can be less harmful to local ecosystems and provide for local employment, at least when compared to more polluting forms of construction material-related mining. Quarries can be backfilled and returned to nature relatively easily. Stone blocks, slabs, and panels can be dismantled and reused with minimal degradation. In practice, however, recovered stone is often downcycled; mixed demolition stone is commonly crushed into aggregate for road bases, or low-grade fill.

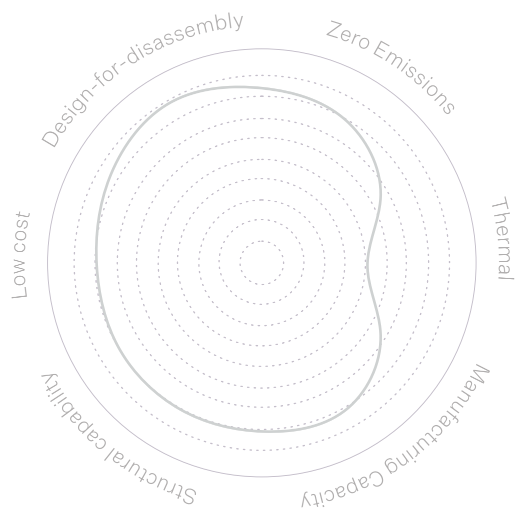
Typical stone production cycle

Stone is used in construction as load-bearing masonry, ranging from large blocks to smaller units laid in courses using lime or cement mortar as a binder. Historically working in compression, stone is also now used as tensioned elements, allowing columns and beams to achieve greater structural capacity



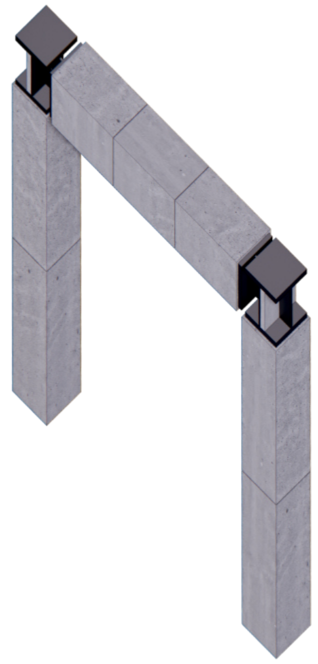
Prefabricated stone systems are cut and drilled blocks that can be tensioned into beams, columns, and slabs. By introducing steel tendons, stone can work structurally beyond compression alone. This approach enables repeatable, load-bearing stone elements with high durability

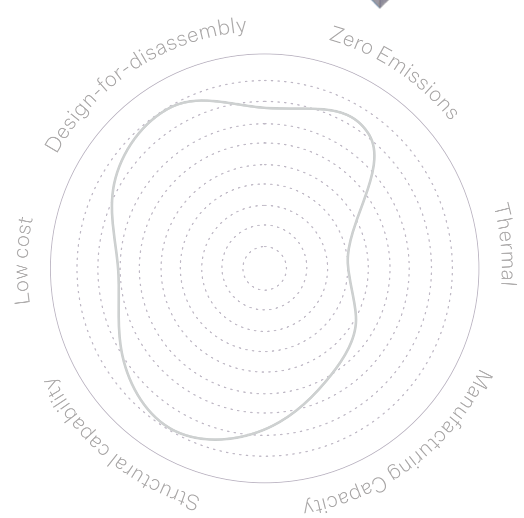
Stone blocks



STONE BLOCKS are large, load-bearing units cut directly from quarries, used in walls, piers, and structural masonry. They provide excellent compressive strength, durability, and longevity, with minimal processing beyond cutting. Their mass makes them highly stable, though energy use in quarrying and transport can be significant. Stone blocks can often be dismantled and reused without significant additional processing, making them a more circular alternative to concrete or fired masonry.

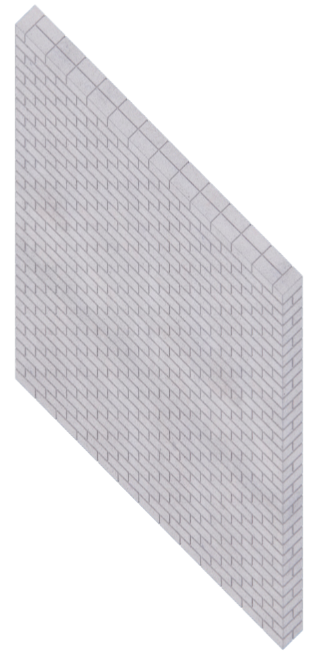
Tensioned stone

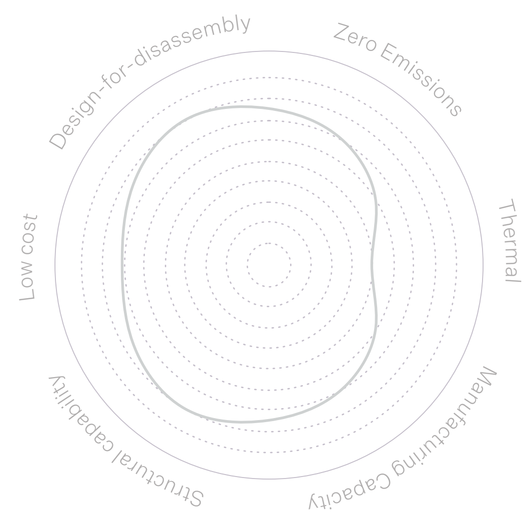




TENSIONED STONE combines stone's natural compressive capacity with steel tendons to create beams, columns, and even floor systems. By keeping the stone in compression, this system enables longer spans and lighter elements than traditional masonry. The method allows stone to compete structurally with concrete and steel while offering significantly lower embodied emissions: Future Observatory's *Stone Demonstrator* project reports approximately 70% less compared to a reinforced concrete frame, and 90% less compared to a steel frame (Future Observatory 2025). Prefabricated or site-assembled, tensioned stone demonstrates how traditional materials can be adapted to a contemporary context.

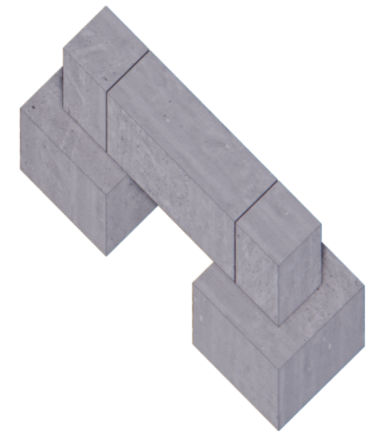
Stone bricks

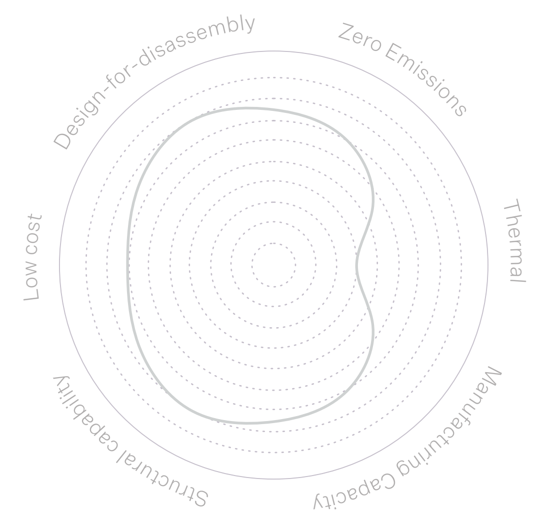




STONE BRICKS are smaller, modular units cut from stone, allowing precise coursing and more flexible assembly than full blocks. They can be used structurally or as infill, combining compressive strength with a durable finish. While labour intensive compared to larger units, stone bricks can be reclaimed and reused across cycles. Their density provides thermal mass but low insulation value, making them most effective in hybrid wall systems. They are also a lower-carbon alternative to traditional fired clay bricks.

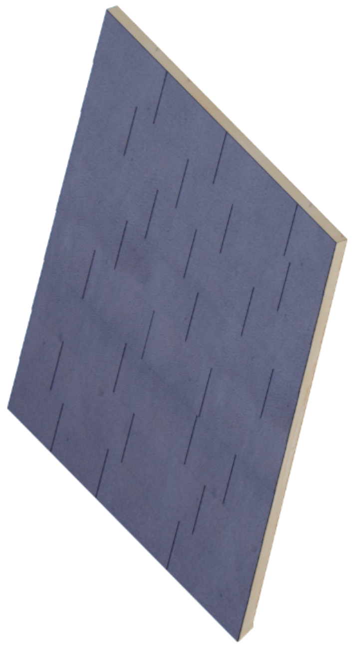
Stone foundation

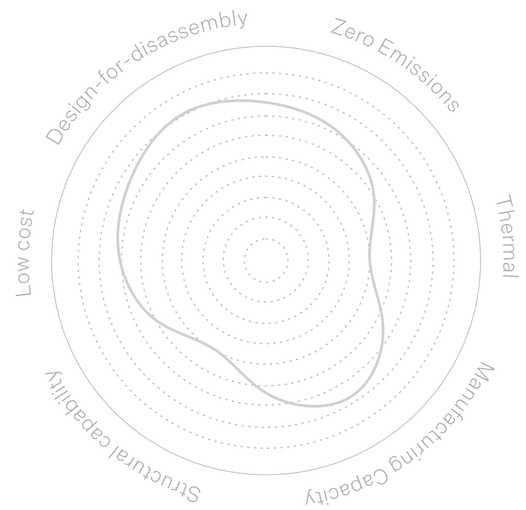




STONE FOUNDATION use rubble, cut blocks, or engineered stone to form bases for walls and structures. Their durability and resistance to moisture make them historically widespread, especially before concrete's dominance. While heavy and requiring skilled placement, stone footings are highly durable and can be reused if carefully dismantled. They represent a low-emission alternative to concrete footings where suitable stone is locally available.

Stone cladding and roofing





STONE CLADDING AND ROOFING has long been used as a durable cladding and roofing material, most commonly in the form of slate tiles or thin stone panels. Slate roofing provides excellent weather resistance, fire performance, and longevity, often lasting many decades with minimal maintenance. As wall cladding, fixing methods vary. This matters for circularity. Many thin stone veneers are adhered with mortars or adhesives, which makes removal difficult and typically results in breakage, and can prevent return to the biosphere. By contrast, ventilated *'rain screen'* stone systems use mechanical brackets or rail systems, which allow for panel removal and reuse if detailed for access and maintained. Quarrying and transport remain the primary environmental impacts, but durability and reusability make stone a viable exterior material.

Stone Demonstrator, London (2025)
Groupwork, Webb Yates, Arup, and Future Observatory

Let’s start small. Stairs: Obviously. You’re about to put a boring steel portal frame in an old house: Save on decoration, make it stone. Your concrete frame: swap the columns for stone and leave them on show. You have a small canopy over a café: Build a little stone vault. Building five units of residential—how about a timber and stone hybrid? Production starts with demand; if you want it, demand it!

Steve Webb
RIBA Journal, 29 May 2021

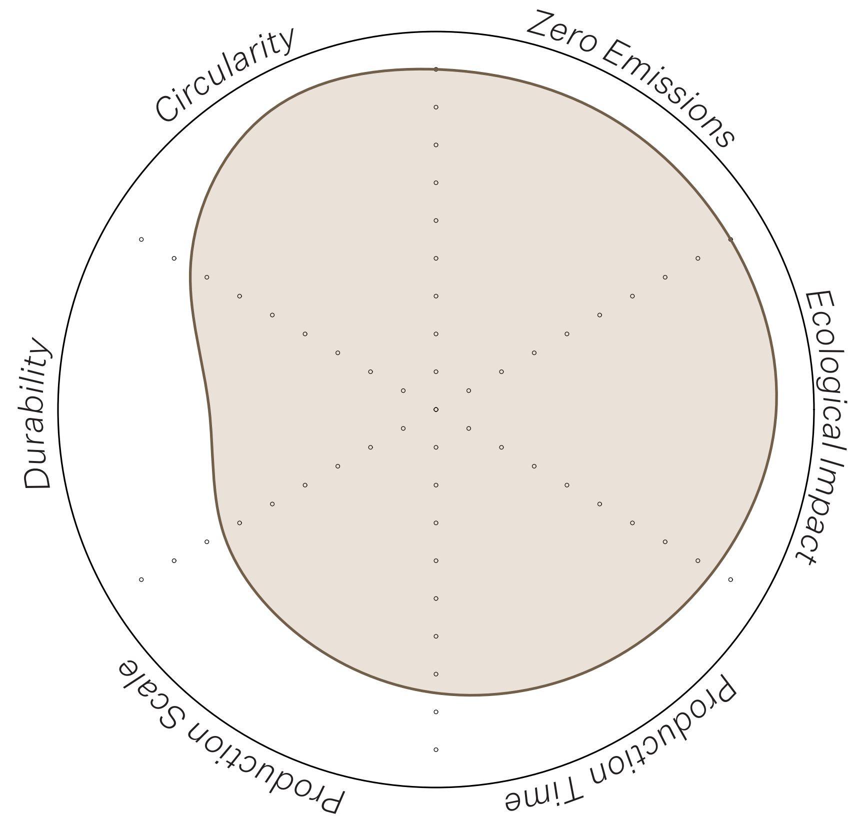
Heide Modern, Melbourne (1964)
David McGlashan

Pictured November 2023

Circle mainly focuses on contemporary treatments of stone, such as tensioned stone. But stone buildings are all around us, in large part due to their durability, adaptability, and beauty. Heide Modern is one of Melbourne’s key modernist buildings, designed by David McGlashan, of McGlashan and Everist, in 1964. Built largely from Mount Gambier limestone, the stone is augmented by a limited palette of other materials: timber, concrete, glass, and terrazzo tiles and leather cupboard pulls. Although extracting stone is akin to mining rather than farming, quarrying for stone is relatively non-polluting, and quarries can be backfilled and returned to nature.


EARTH

Earth



EARTH construction encompasses a wide family of techniques that utilise locally sourced soils. Rammed earth and compressed earth blocks rely on compaction rather than firing in a kiln, resulting in relatively low embodied emissions. Material preparation typically involves adjusting clay, silt, sand, and gravel ratios, with stabilisers added only where required for strength or consistency. Because earth is used largely as excavated, it avoids the intensive energy demands of cement production, and at end of life can be returned directly to the ground or reprocessed into new elements.

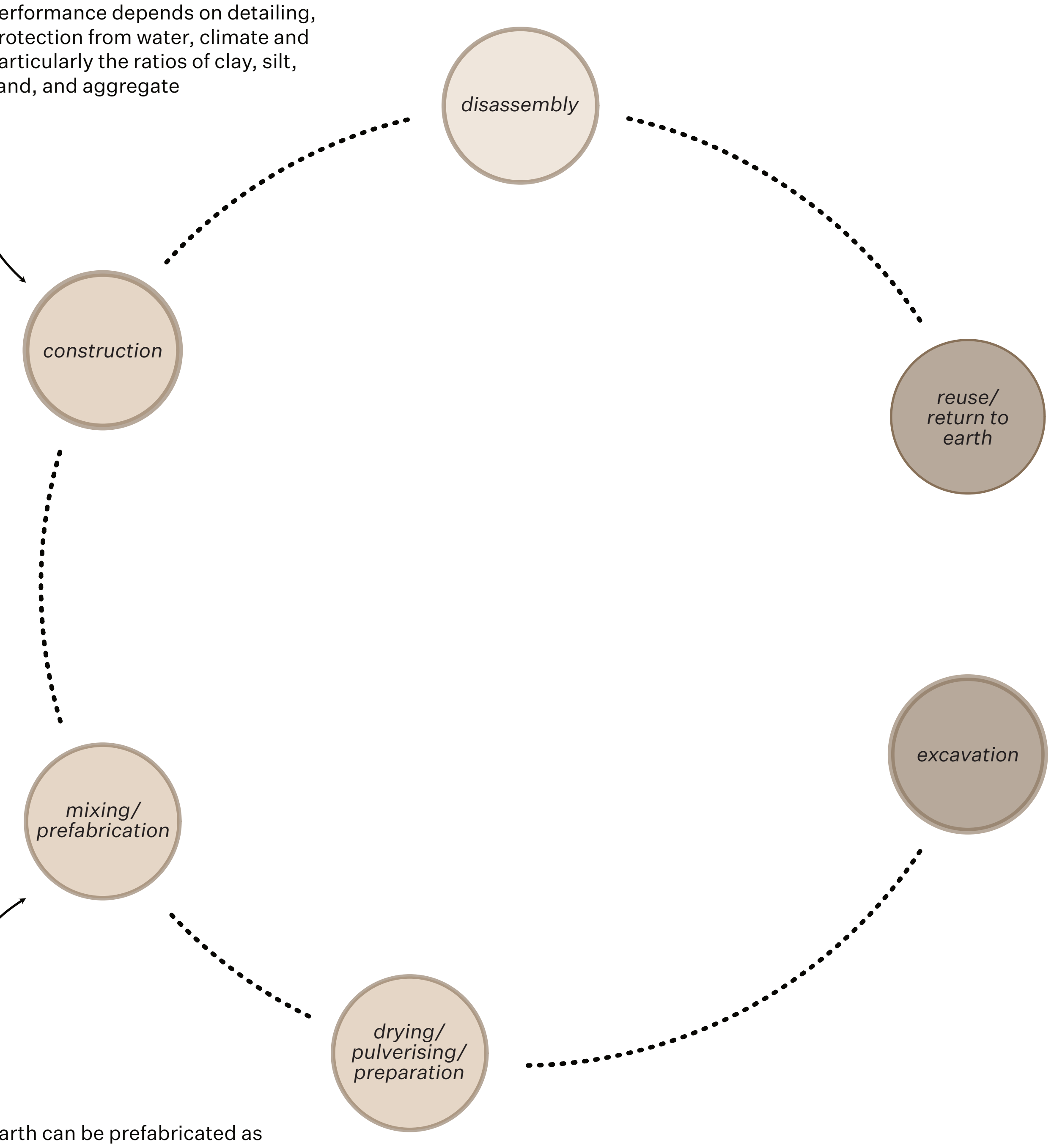
Earth supports a range of construction systems. Rammed earth forms monolithic walls with strong compressive capacity and high thermal mass; in urban settings, precast rammed earth panels, such as those used in Déchelette Architecture's *Quatre Cheminées* project, allow controlled curing and faster installation while retaining the material's low-emissions profile. Compressed earth blocks offer modularity, consistent sizing, and the ability to be dry-stacked or laid with thin earthen mortars. Traditional wattle and daub combines a woven timber lattice with an earthen mix to create lightweight, breathable wall assemblies, demonstrating long-standing techniques of material frugality and local sourcing.

Earth is also widely used in finishes. Earth plasters and renders can provide a finish for interior and exterior surfaces that regulate humidity, soften acoustics, and eliminate reliance on synthetic coatings. These finishes can be renewed or repaired easily, extending their service life and maintaining material circularity.

Performance depends heavily on moisture management: raised plinths, adequate overhangs, and suitable renders are essential to prevent erosion. While earth has limitations, labour intensity, curing time, and sensitivity to rainfall, it remains one of the most accessible, low-emission material systems.

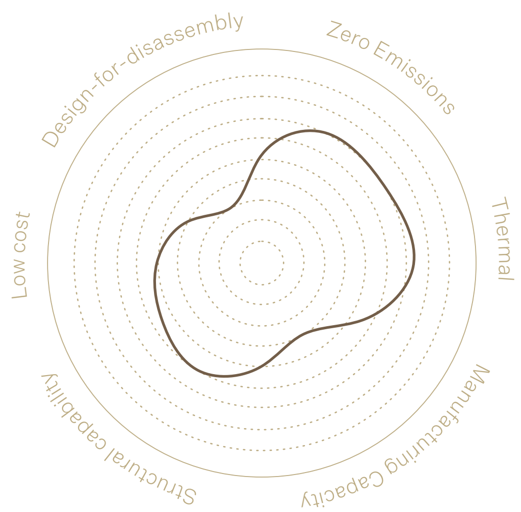
Typical earth production cycle

Earth construction ranges from load-bearing rammed earth walls and block systems to lower-tech methods such as cob, wattle and daub, and earth plasters or renders. Performance depends on detailing, protection from water, climate and particularly the ratios of clay, silt, sand, and aggregate



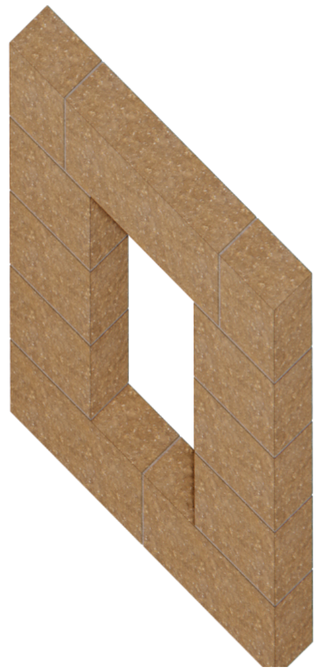
Earth can be prefabricated as compressed earth blocks or larger precast rammed earth panels. Unstabilised earth maintains low embodied emissions and full circularity, while the addition of cement increases strength and durability but significantly raises embodied emissions and limits options for end-of-life reuse

Rammed earth



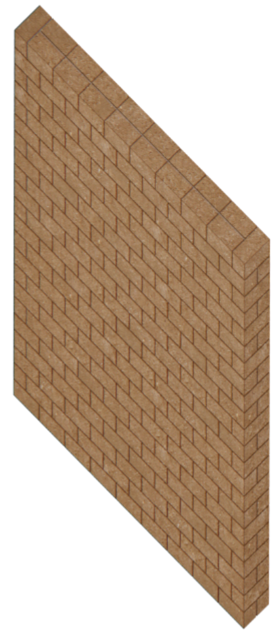
RAMMED EARTH is made by compacting layers of moist earth within formwork to create dense, monolithic walls with strong thermal mass. Its compressive strength makes it suitable for structural applications, though it requires protection from moisture and erosion. While less durable than fired masonry or concrete, rammed earth has a lower embodied carbon and can be sourced locally, giving it strong circular potential.

Precast earth



PRECAST EARTH is similar to rammed earth, but is manufactured off-site as large blocks or panels and delivered to site as finished units. Unlike in-situ rammed earth, which typically requires continuous, large-format on-site formwork, precast elements are compacted and cured in controlled conditions, improving consistency and reducing moisture variability. On site, installation becomes closer to panelised construction; units are craned into position and joints/fixings are completed, which can reduce construction time and site congestion, making the system more workable on tight urban sites. Main considerations include panel weight, transport logistics, crane access, and careful coordination of lifting points, joints, and moisture detailing to ensure long-term durability.

Compressed blocks

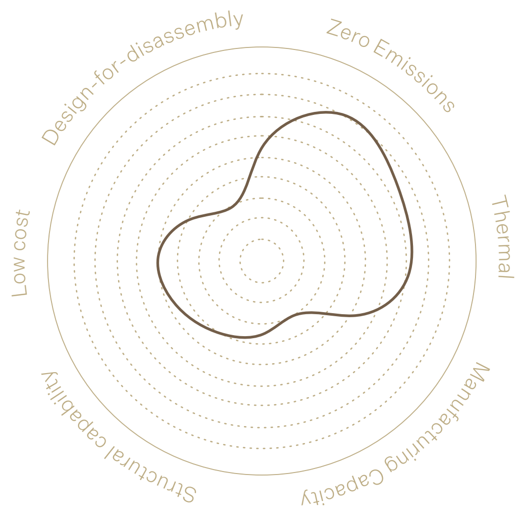


COMPRESSED BLOCKS are machine-pressed units made from stabilised or unstabilised earth. They are modular, offering faster, simpler construction than in-situ rammed earth, and can be stacked like masonry units. Although they do not match the durability or structural strength of fired clay bricks, compressed earth blocks have dramatically lower embodied emissions because they avoid kiln firing and can often be disassembled for reuse, broken and mixed into new blocks or returned to the ground at end of life. There is increased interest in these techniques—particularly **compressed stabilised earth blocks (CSEBs)**, as described in Senegal collective Studio Suddo Neuve's *Bauhaus Earth Manual: Back to Earth—Urbanisation without Depletion* (2025).

Cob construction

COB CONSTRUCTION blends earth, water, and straw into a thick, fibrous mixture that is hand-applied to form walls. While it is not applicable to most mainstream building applications in highly industrialised contexts, it remains worth considering for small-scale, non-structural elements, interior partitions, thermal-mass inserts, or repairable retrofit work. It is labour-intensive but offers excellent thermal inertia and breathability, and its simple composition allows the material to be reworked, reused, or composted at end of life, giving it strong circular potential. Performance depends on careful siting, moisture protection, and ongoing maintenance to prevent weathering.

Wattle and daub



WATTLE AND DAUB is a traditional walling system that combines a lightweight timber or bamboo lattice (the wattle) with an earthen mix of clay, sand, fibre, and water (the daub). The daub is pressed into and over the woven frame to create a breathable, flexible wall surface with good acoustic moderation and moderate thermal mass. It is non-structural and relies on a separate frame for load-bearing capacity. Performance depends on careful moisture detailing, including *structural preservation* techniques (Mossin et al, 2023) such as raised foundations and protective overhangs, ensuring that the daub does not erode if frequently exposed to water. While labour-intensive—not *necessarily* a drawback, as noted earlier— wattle and daub offers a low-emissions, repairable system suited to small-scale or infill applications.

Earth plasters and renders

EARTH PLASTERS AND RENDERS are finishing materials made from fine clay or soil, sometimes stabilised with natural fibres or lime. They are applied to walls for smooth, breathable surfaces with excellent humidity regulation. As noted by in our discussion with Joakim Kaminsky, clay boards and clay plasters can replace plaster/gypsum boards and finishes, with additional thermal, air quality, acoustic, and aesthetic qualities. Their embodied emissions are low, and they can be composted or reintegrated into soil at end of life. Their primary role lies in interior finishing. As noted by Hassell and Fieldwork, these indoor surface building layers 'move more quickly' than structural layers, indicating the significant potential impact of earth/clay-based construction elements.

Quatre Cheminée housing Déchelette Architecture (2024)
Four-storey building with eight social housing units, caretaker's lodge, and a shop, using a timber structure and self-supporting prefabricated raw earth blocks, placed on a stone base on the street side of the building. The rammed earth is locally sourced from the excavation of the Greater Paris metro.

Circle / Part 3 / Industry-aligned materials

Concrete
Steel
Glass
Brick
Plaster

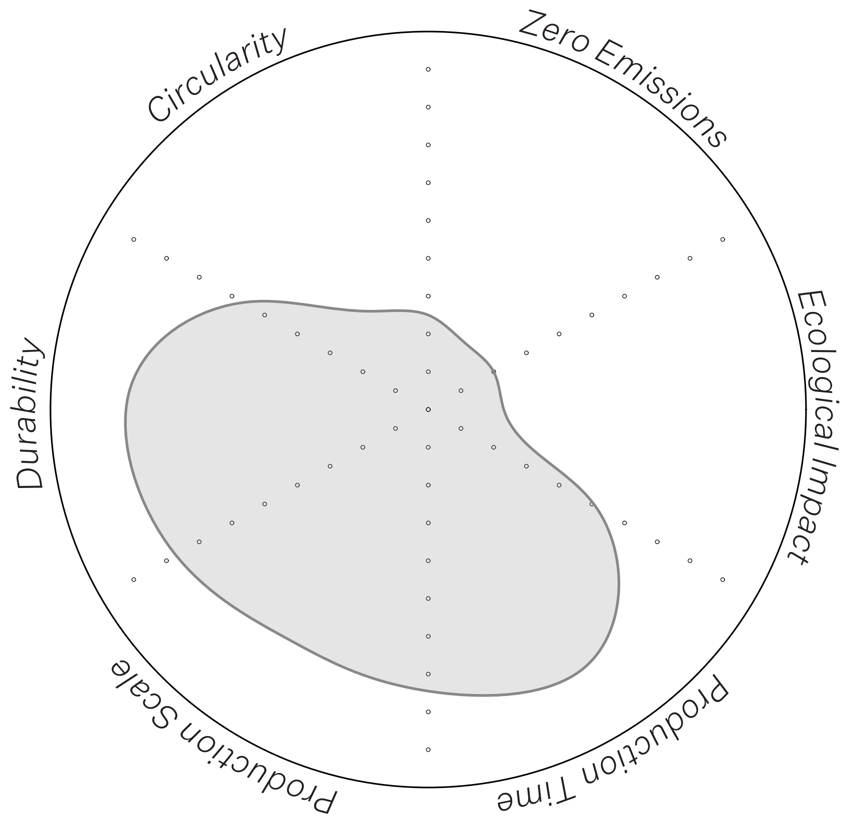
Ginza Sony Park, Tokyo (2024)

Pictured December 2025

Partial renovation of existing Sony Park building at basement levels, retaining some of the original 1966 building elements, integrated with Ginza Line subway system. Upper floors are adaptable public platform in concrete and steel.

CONCRETE

Concrete

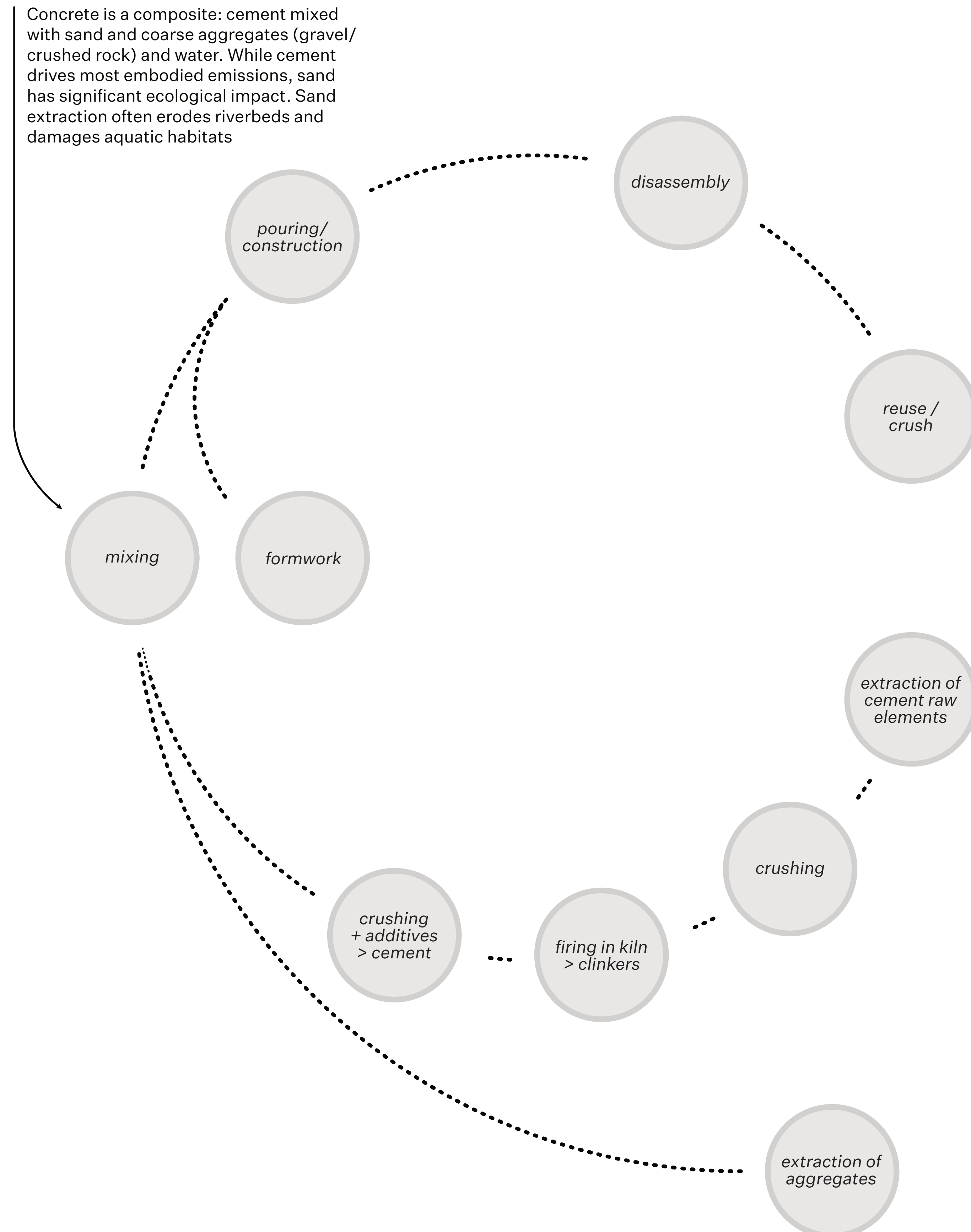


CONCRETE is the most widely used construction material globally, valued for its adaptability, strength, and formal flexibility. Made from cement, aggregates and water, it performs exceptionally well in compression and can achieve durability, fire resistance, and long spans when combined with steel reinforcement. Cement production contributes significantly to embodied emissions due to limestone calcination and high-temperature kiln processes, in addition to its impact on landscapes and ecosystems, in part due to cement's inherent reliance on sand. Proposed substitutes like fly-ash contain potentially toxic heavy metals and are dependent on ongoing fossil fuel production (Ellen Macarthur Foundation, 2016). Concrete's advantages include thermal mass, predictable structural behaviour, and compatibility with legacy systems, but its environmental impact is hugely damaging at all lifecycle stages.

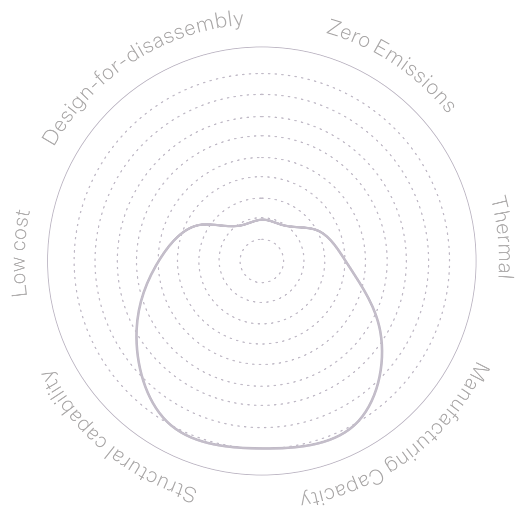
Although concrete is technically recyclable, most recovery results in downcycling, with demolished elements crushed into low-grade aggregate rather than reused. Reinforced concrete is typically cast monolithically, limiting disassembly and high-value reuse. Precast elements can be more easily detached and reinstalled, but this relies on reversible connections, standardised sizing, careful demolition, and viable sustainable transport—conditions which are rarely in-place.

Concrete appears in structural frames, floor slabs, precast modules, tilt-up panels, pavements, and civil infrastructure. Its ability to integrate reinforcement supports multi-storey and long-span construction, though it performs poorly in tension without steel. Long-term durability depends on mix design, curing, and exposure, with carbonation, steel corrosion, and cracking influencing longevity. Improving concrete's circularity involves increasing reuse of precast components, designing for disassembly, adopting lower-emissions binders, and shifting demolition practices toward material recovery. Primarily, however, the primary production strategy for concrete from now on must be avoidance and reuse.

Typical concrete production cycle



In-situ concrete

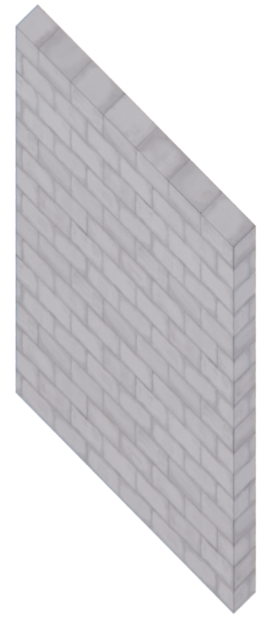


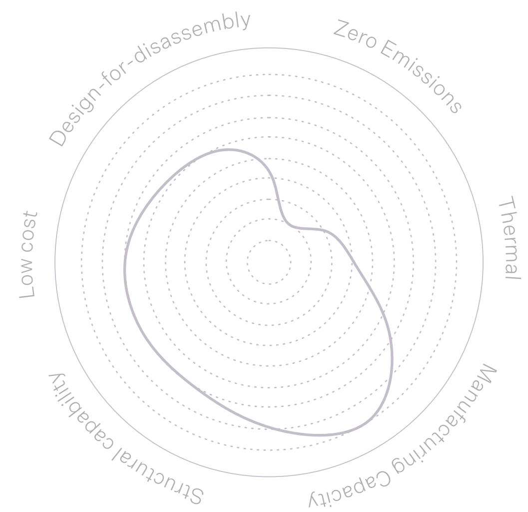
IN-SITU CONCRETE is poured and cured directly on site, allowing structures to be customised to almost any geometry or load requirement. With reinforcement, it can be adapted for slabs, beams, or columns, giving designers unmatched certainty and flexibility. This versatility comes at a significant environmental cost, however, as cement production is one of the single largest contributors to global embodied emissions, damaging land-use, and ecosystem degradation. Product-centred research, such as testing limestone calcined clay's ability to replace Portland cement, shows some promise, yet scholars conclude there is no viable path to net-zero concrete by 2050 (Driessen and Grönlund 2024). There is no *"silver bullet"* (Habert et al 2024). Marsh et al (2024) note the need for systemic approach to the *"'soft' social, political and legal aspects"*, including overall reduction.

Precast concrete

PRECAST CONCRETE panels are factory-produced units transported to site for rapid assembly. They deliver a high quality and consistent building element, with reduced site labour and better performance control when compared to in-situ pours. Panels can be engineered for structure or enclosure, but despite efficiency in production, their cement content still results in high embodied emissions. Their large scale also complicates reuse, however, though modularity can extend their lifecycle in some cases.

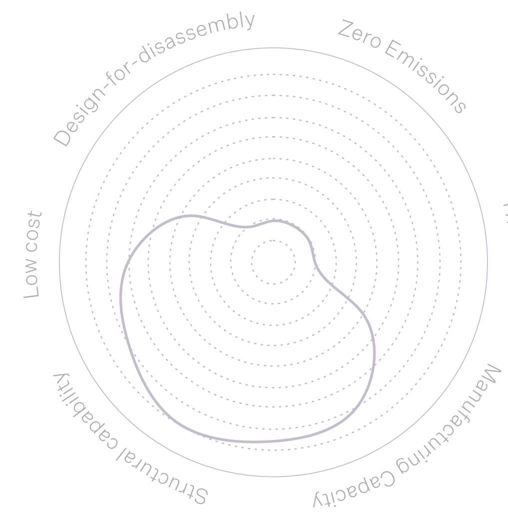
Concrete blocks





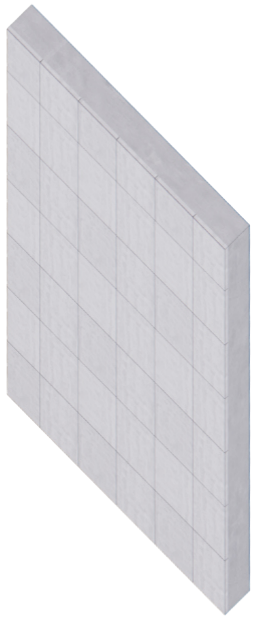
CONCRETE BLOCKS are modular masonry units made from cement, aggregates, and water. They offer a highly standardised, low-cost, and durable solution for walls and partitions, with better circularity potential than panels since they can sometimes be dismantled and reused. While structurally reliable, blocks still carry the high environmental burden of cement and have limited end-of-life pathways beyond down-cycling into aggregate. Stone blocks and bricks provide less-damaging alternatives.

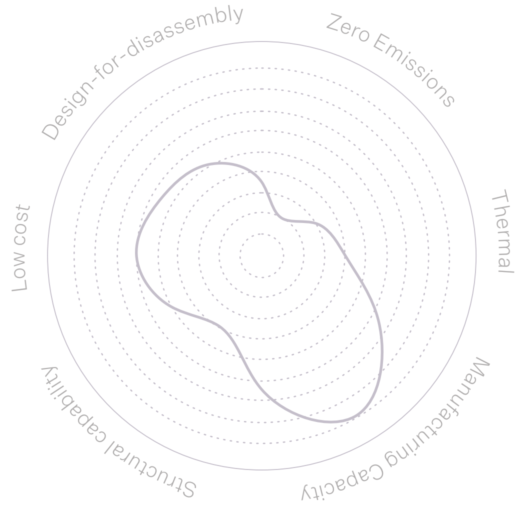
Concrete foundations



CONCRETE FOUNDATIONS underpin most modern structures, valued for strength, predictability, and ease of forming. They can be designed for almost any soil condition, from shallow strip footings to deep piles, providing essential load transfer and stability. Despite these structural assurances, foundations are among the hardest concrete elements to recover, meaning they typically lock in some of the highest long-term carbon costs.

Concrete tiles





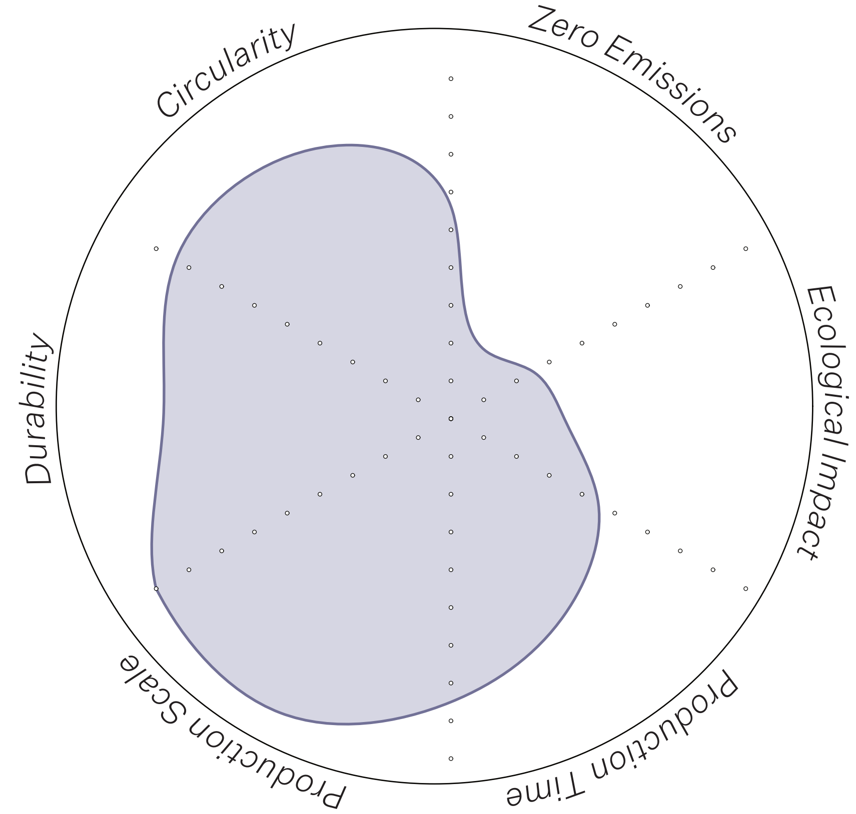
CONCRETE TILES FOR CLADDING are smaller, factory-made units for ground and surface applications. They provide durability, abrasion resistance, and their modularity offers greater reuse potential than in-situ systems, though they still rely on environmentally-damaging cement-intensive production. Their value lies in resilience and versatility, offset by impacts that remain highly challenging to mitigate other than through demand-reduction and substitution by some of the 'planet-aligned' alternatives described earlier.

Polystyrene, cement, and steel are big contributors to greenhouse gas emissions, so they should only be used where absolutely necessary. Timber is currently an energy-hungry material and is becoming a scarce resource worldwide, it cannot foreseeably replace the current volume of concrete construction. Exciting directions that are currently being explored include rammed earth, straw bale construction, and minimally reinforced structural stone as a low-carbon alternative to concrete.

Florian Urban and Barnabas Calder
Form Follows Fuel (2025)


STEEL

Steel

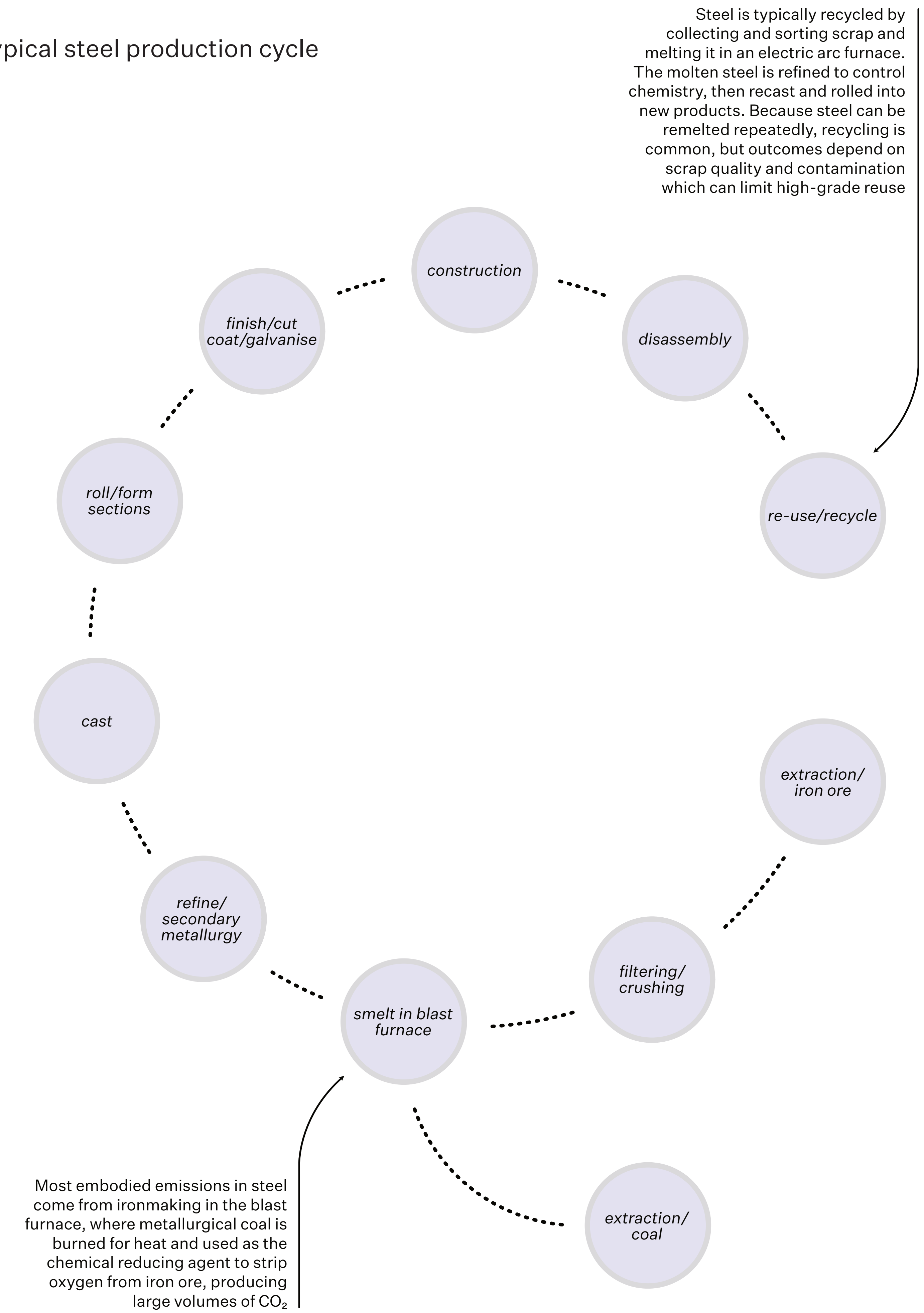


For 150 years, **STEEL** has been a mainstream construction material, valued for its tensile strength, ductility, and consistent performance across a wide range of building types. Produced through high-temperature processing of iron ore or recycled scrap, steel can achieve long spans, slender structural profiles, and efficient load paths that are difficult to precisely replicate with other materials. Structural systems using steel include beams, columns, trusses, lightweight purlins, and composite assemblies with concrete slabs. Despite its durability, steel's production remains a major source of embodied emissions due to smelting, alloying, and reheating. Its performance also depends on corrosion protection, fire insulation, and appropriate detailing to avoid fatigue and buckling in service.

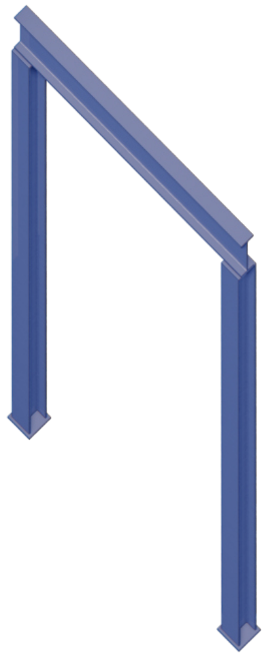
Steel is theoretically infinitely recyclable without loss of quality, but most recycling involves melting scrap back into new steel, an energy-intensive process that creates significant further emissions. High-value reuse, where beams or sections are taken from one building and reinstalled in another, is technically possible but uncommon. Welded connections, coatings, uncertain material grades, and rapid demolition practices all limit recoverability. Where bolted or reversible fixings are used, reuse becomes more feasible, but these approaches are not standard within the industry. Transportation, cleaning, and certification of reclaimed elements further affect viability.

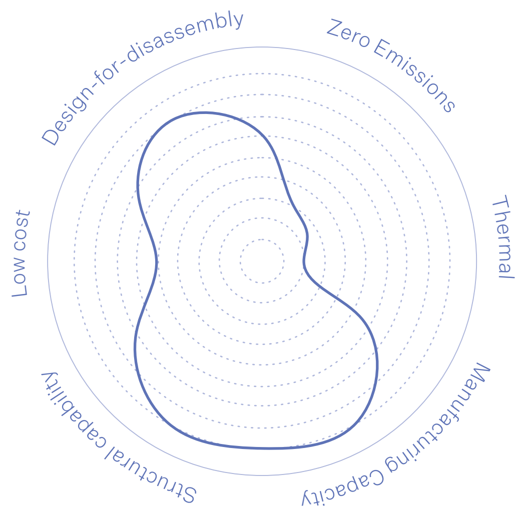
Steel is deployed in primary frames, composite floors, façade systems, reinforcement, and building services. Its strength allows for dense urban construction and flexible interior layouts, though failures in fire protection or corrosion control can reduce longevity. As steel remains a default material for contemporary construction, its circularity must be prioritised, including coherent documentation of material properties, wider adoption of bolted assemblies, and salvage processes that preserve structural elements, as well as avoidance via reduction and substitution.

Typical steel production cycle



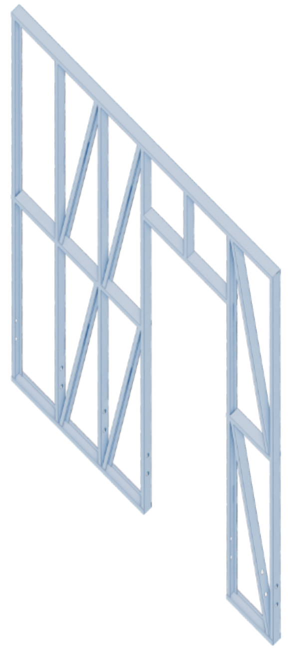
Hot-rolled structural sections

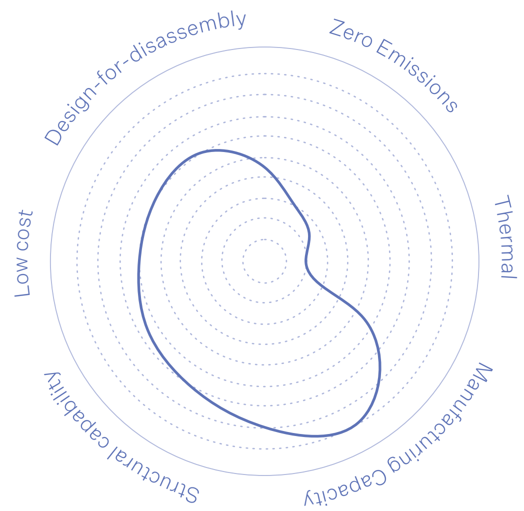




HOT-ROLLED STRUCTURAL SECTIONS are beams, columns, and trusses formed at high temperature, enabling steel to span long distances and carry heavy loads. Its widely used because for its versatility and predictability, it can be detailed to meet specific structural needs and certification requirements. Its durability and reusability support circular construction, though production still carries high embodied emissions, particularly for primary steelmaking.

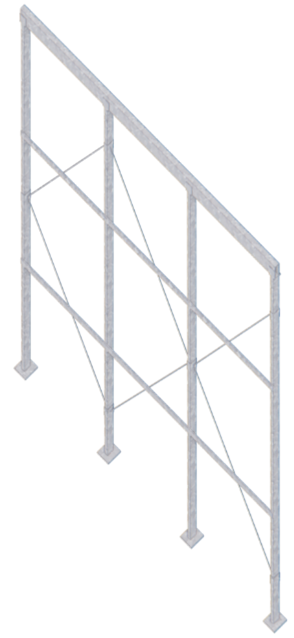
Cold-formed light gauge steel

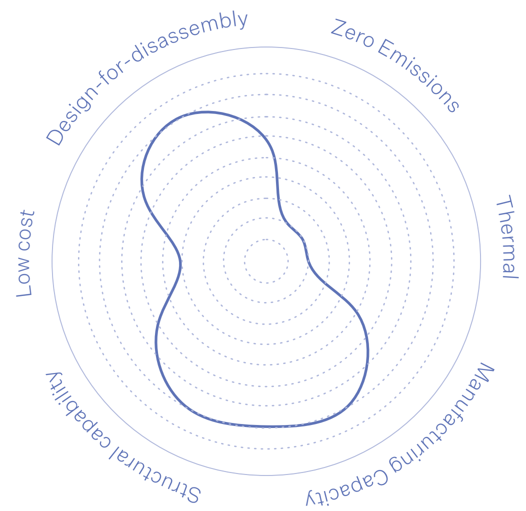




COLD-FORMED LIGHT GAUGE STEEL is produced by bending thin steel sheet at room temperature into studs, channels, and other profiles. It is widely used for lightweight framing, partitions, and modular construction because it supports fast, repeatable assembly. In Australia, uptake has increased in part due to timber framing shortages and rising timber costs. While it uses less material than hot-rolled sections, it is structurally lighter-duty and still energy-intensive to produce, though it is highly recyclable at end of life, at least in theory.

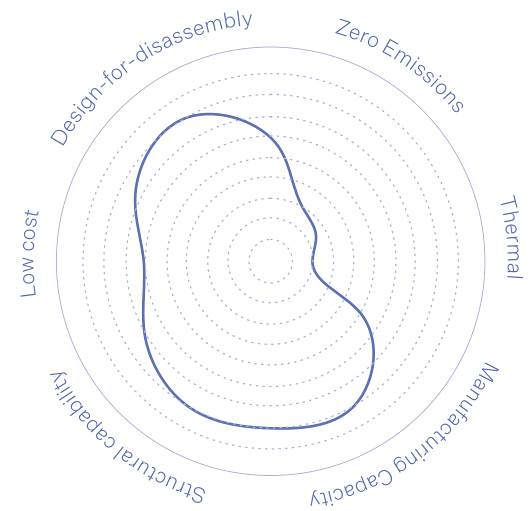
Galvanised steel





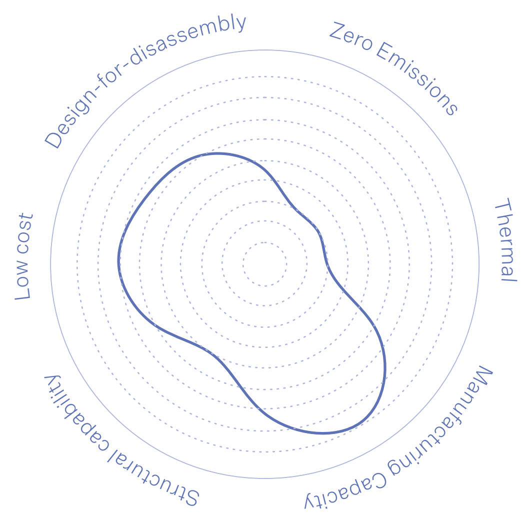
GALVANISED STEEL is steel coated with a layer of zinc (typically via hot-dip galvanising) to reduce corrosion and extend longevity in exposed, wet, or high-humidity environments. This makes galvanised steel common for exterior structural elements, light-gauge framing, fasteners, brackets, façade subframes, balustrades, and ground-adjacent components where durability and reduced maintenance are critical. Performance depends on coating thickness and detailing to avoid trapped moisture.

Steel foundations/footings



STEEL FOUNDATIONS AND FOOTINGS are deep footings formed from hollow steel shafts with helical plates that are rotated into the ground, providing load-bearing capacity without excavation or concrete. Installation can be fast, vibration-free, and suitable for constrained sites, allowing accurate placement with minimal soil disturbance. Screw piles work in compression and tension, making them effective for lightweight structures, reactive soils, and areas requiring uplift resistance. Their performance depends on corrosion protection and soil conditions. While steel carries significant embodied emissions, screw piles can be fully removed, reused, or recycled at end of life, offering a reversible foundation system. Limitations include reduced suitability for highly aggressive soils and heavy, concentrated loads.

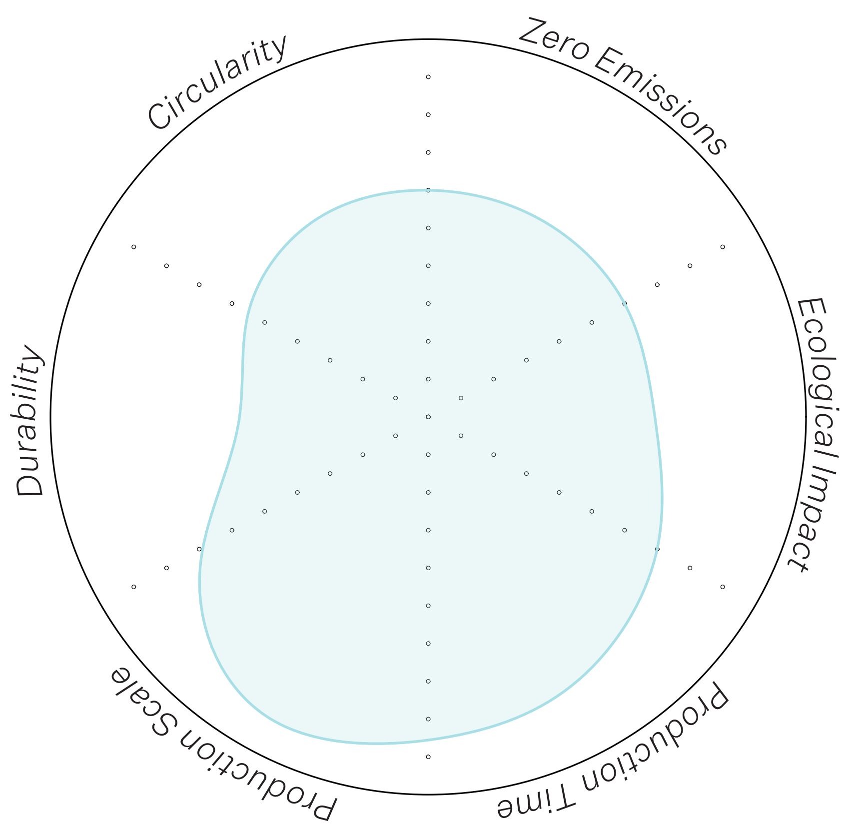
Steel roofing and cladding



STEEL ROOFING AND CLADDING uses corrugated panels or standing seam profiles for enclosure systems. They are lightweight, durable, and easily transportable, with high reuse or recycling potential. Their thinness makes them material-efficient compared to structural sections, but coatings and finishes can complicate recyclability. These applications show steel's adaptability beyond structure, though they still carry the embodied emissions and ecological footprint of the wider steel industry and numerous, more obviously 'planet-aligned', bio-based alternatives exist for cladding and roofing.

GLASS

Glass

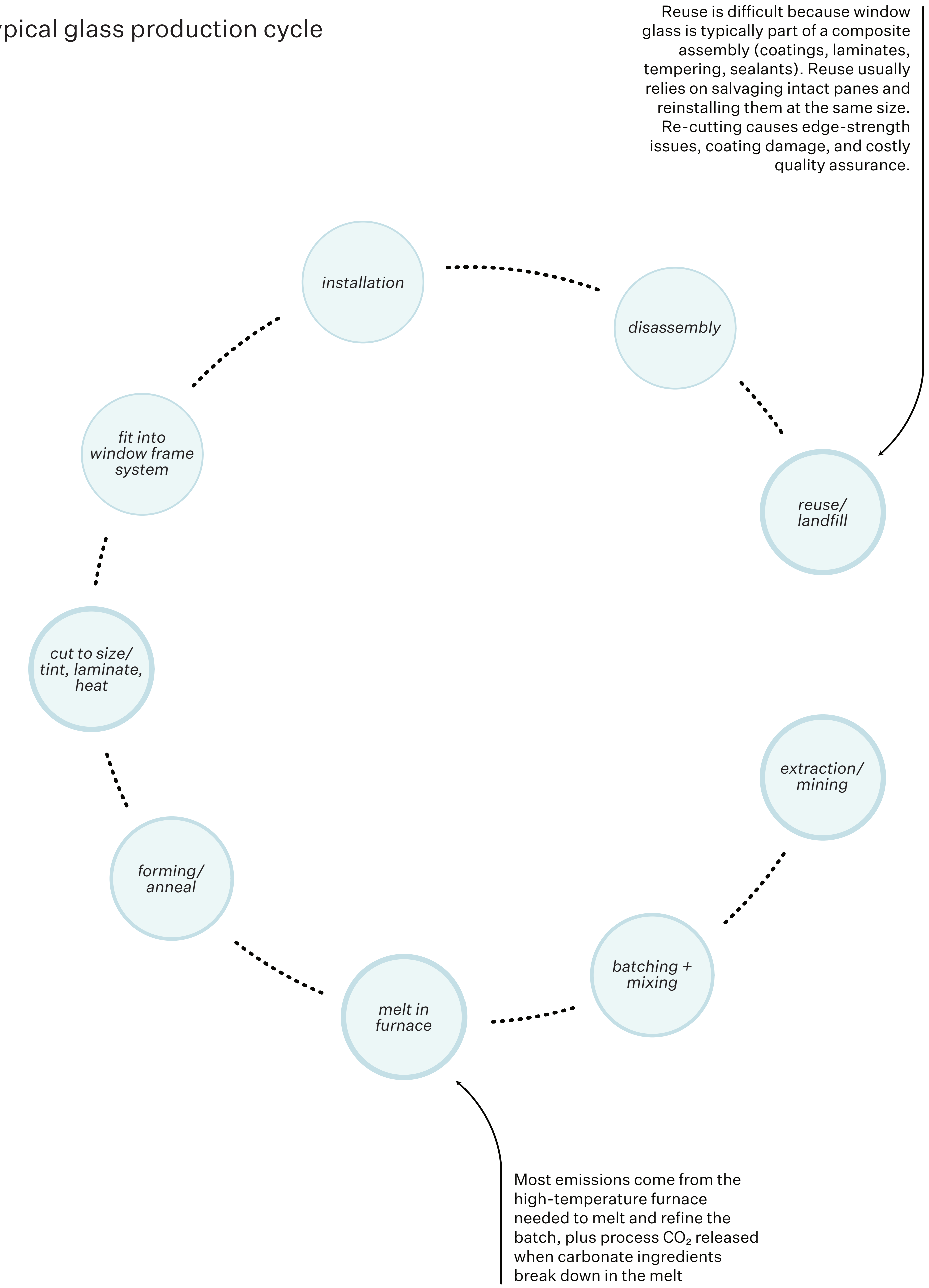


GLASS is manufactured by melting silica sand with soda ash and limestone at very high temperatures. It appears in many forms—typically, float glass, toughened glass, laminated assemblies, and double- or triple-glazed units—allowing for façade systems that range from curtain walls to skylights and interior partitions. However, the high temperatures required for melting and forming contribute to significant embodied emissions, and multi-layered glazing systems introduce complexities that affect circularity and end-of-life recovery.

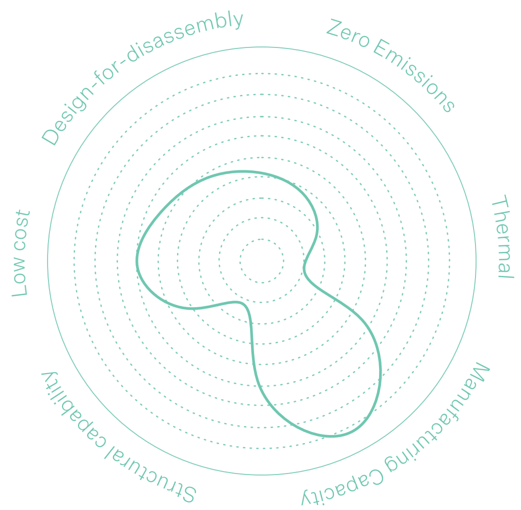
Although glass is technically recyclable, most building glass is contaminated by coatings, frits, laminates, interlayers, and sealants that require separation before remelting. Insulated glazing is particularly difficult to process, as their components are permanently bonded. As a result, much façade glass is downcycled or landfilled rather than reused. Direct reuse of intact panels is possible but uncommon due to breakage risk, outdated safety certification, non-standard panel sizes, and difficulties in removal without damage. Adhesive-based fixing systems and silicone joints also hinder reuse.

Glass is used widely in façades, windows, balustrades, screens, atria, and shading systems. Its performance depends on coatings, thickness, edge treatment, and compatibility with framing or structural glazing assemblies, all of which influence thermal and acoustic performance. Improving circularity relies on reversible fixing systems, designing for disassembly, and pathways for recovering glass without damaging coatings or interlayers. Glass seems indispensable in modern buildings, due to its functional and architectural versatility, suggesting design-led responses to a reduction in the volume of glass will be required, as a form of simplification or avoidance strategy. Perhaps glass might be once again used to create a window in a wall, rather than trying to *be* the wall.

Typical glass production cycle



Float glass

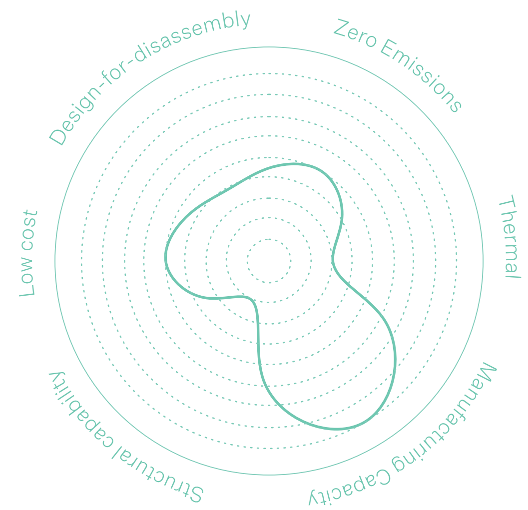


FLOAT GLASS is the base product for most glazing, produced by floating molten glass on a bed of tin. It delivers clear, flat sheets essential for windows and facades, but its manufacture demands high temperatures and significant energy use. Although such glass is technically recyclable, its coatings, laminates, and contamination make recovery difficult.

Insulated glass

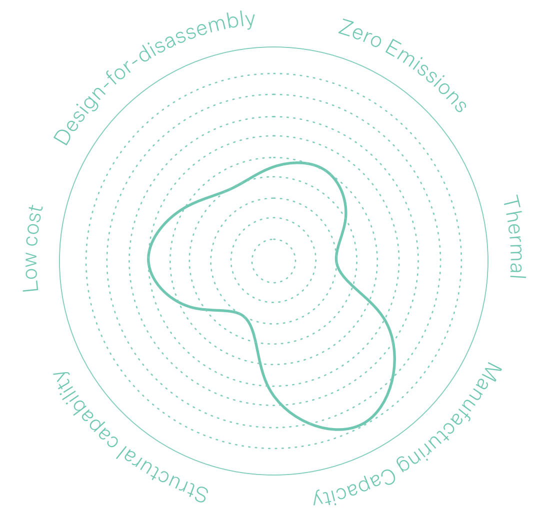
INSULATED GLASS pair multiple sheets of glass with sealed cavities filled with air or gas, boosting thermal and acoustic performance. They are central to reducing operational energy in buildings, yet their composite construction of glass, spacers, and sealants makes them difficult to disassemble. As strategic emphasis shifts from largely focusing only on operational energy, and towards minimising or eradicating embodied energy, ecosystem and biodiversity loss, waste and pollution, insulated glass units highlight the trade-off between performance in-use and challenges at end of life as a building element.

Laminated glass



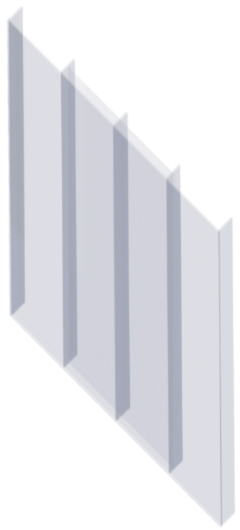
LAMINATED GLASS bonds sheets together with plastic interlayers to improve safety and security. While this increases impact resistance and prevents shattering, it also prevents remelting into new flat glass. Most laminated glass ends up downcycled or discarded, reflecting the gap between technical performance and circular outcomes.

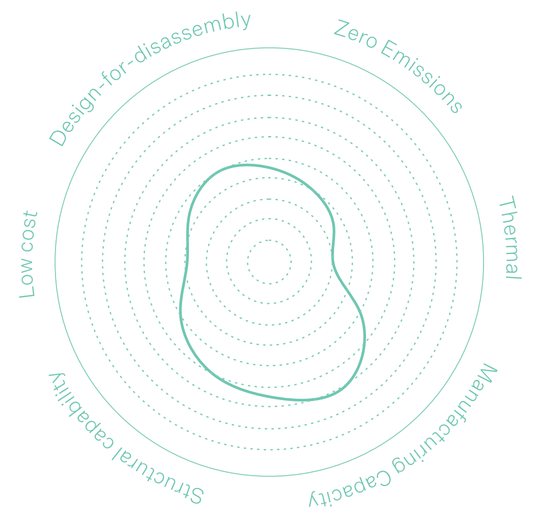
Tempered glass



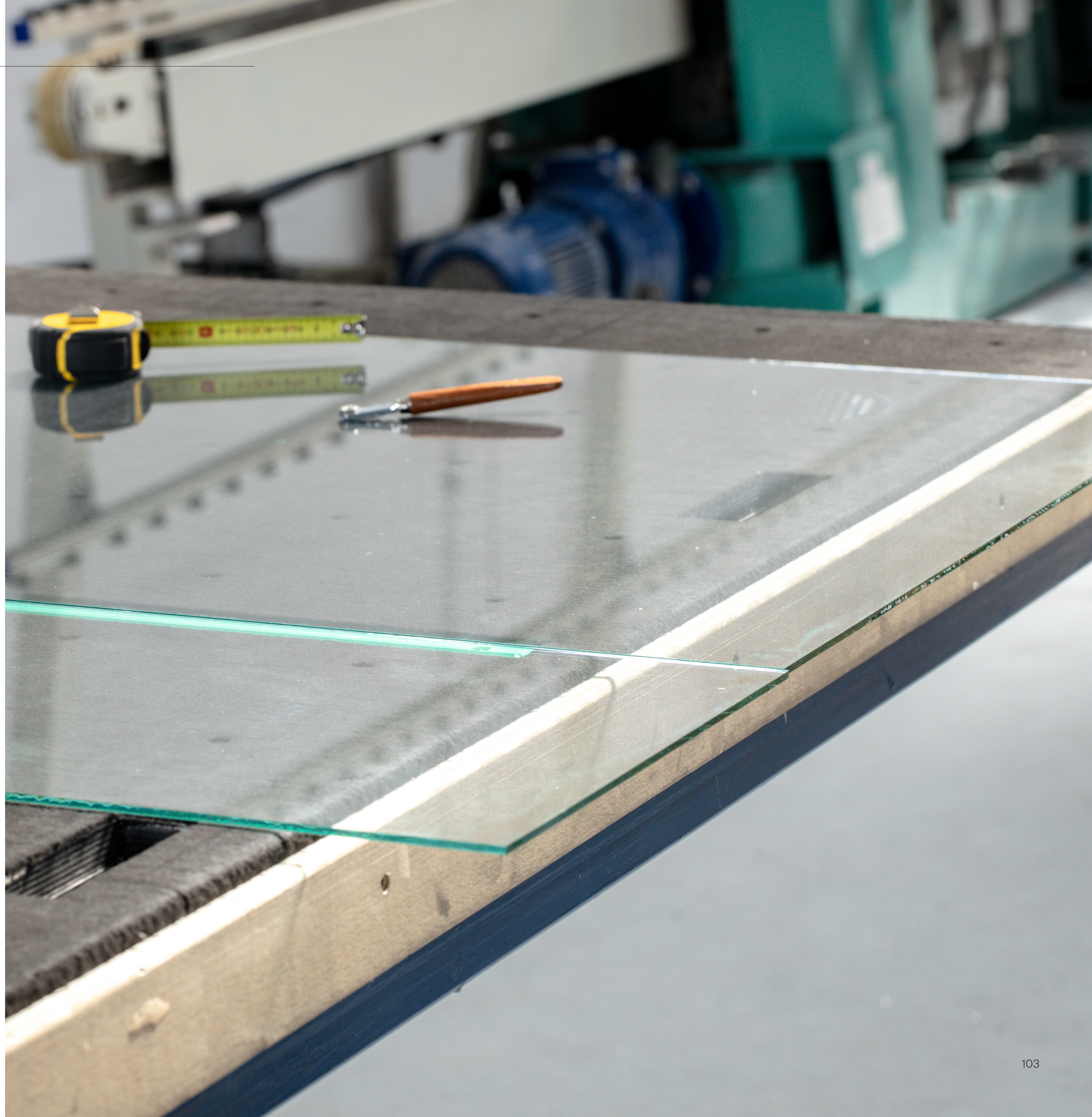
TEMPERED GLASS is heat-treated to increase strength and improve fracture behaviour, making it common in facades, balustrades, and doors. Its processing improves safety but alters material properties, preventing it from being recycled into float glass. It demonstrates how enhanced performance often reduces circularity.

Structural glass



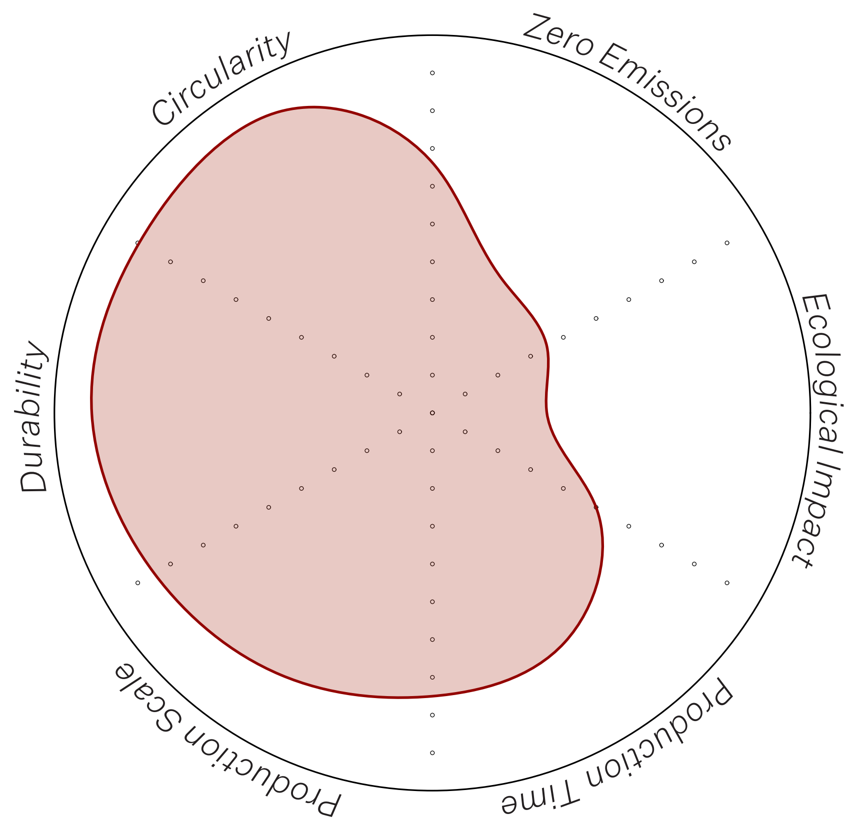


STRUCTURAL GLASS uses thick or engineered sheets as walls, fins, or floors. These elements carry high embodied energy but unlock applications that no other material can achieve. Despite recyclability issues, structural glass shows the tension between architectural ambition and low impact materials, underlining why glass remains one of the hardest materials to substitute with a circular material alternative. So, alongside innovation in circular product design and materials science, inventive architectural design, and marketing, may have to create a future in which buildings utilising significantly less glass is desirable.




BRICK

Brick

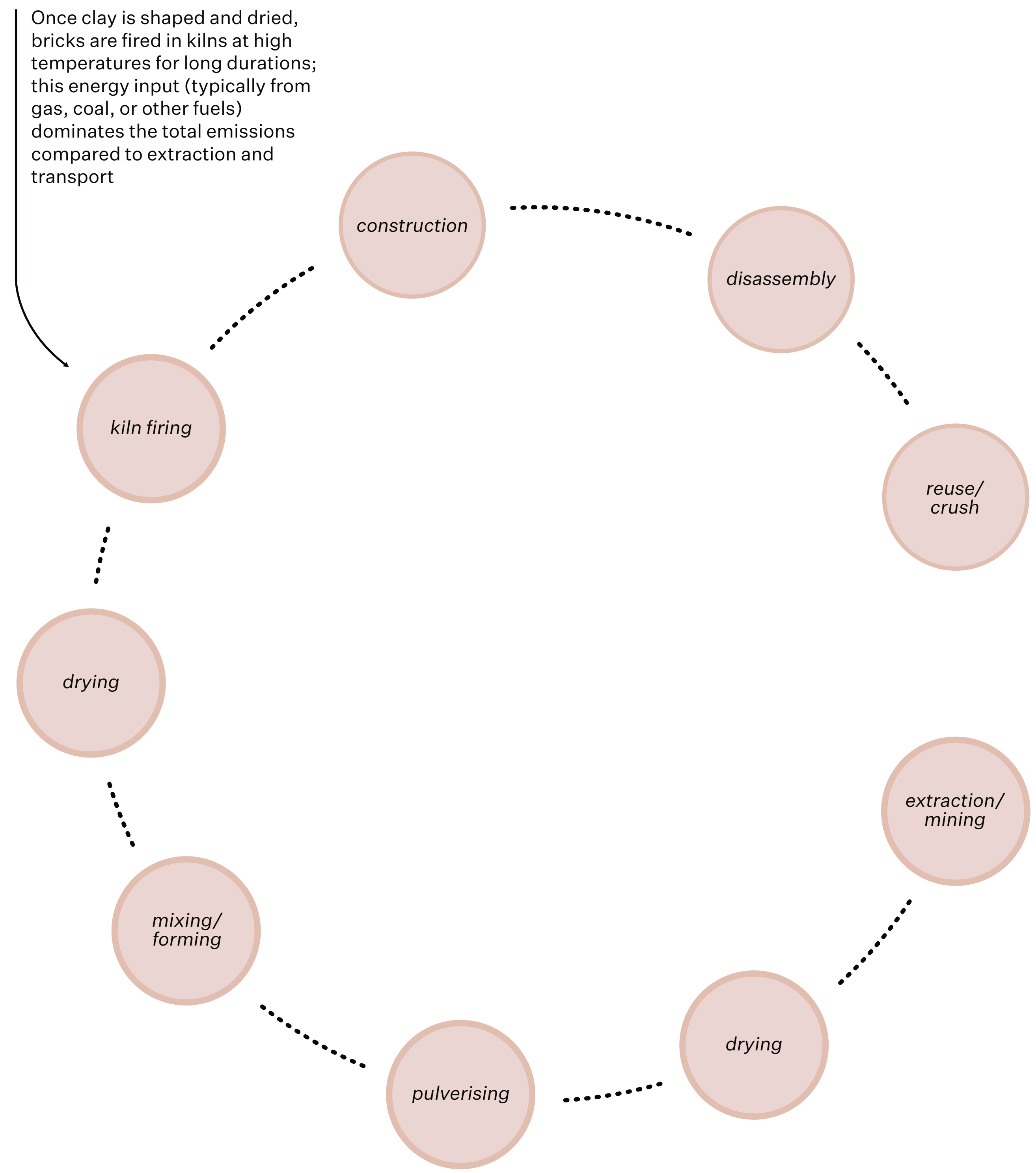


BRICKS remain one of humanity's longest-standing construction materials, valued for durability, fire resistance, adaptability, and its ability to form both structural and non-structural walls. Produced by shaping clay and firing it in high-temperature kilns, bricks offer strong compressive capacity, good weathering performance, and consistent modular sizing. However, kiln firing contributes significantly to embodied emissions due to sustained high temperatures and fuel demand. Performance depends on clay type, firing conditions, mortar specification, and detailing that manages moisture and thermal movement.

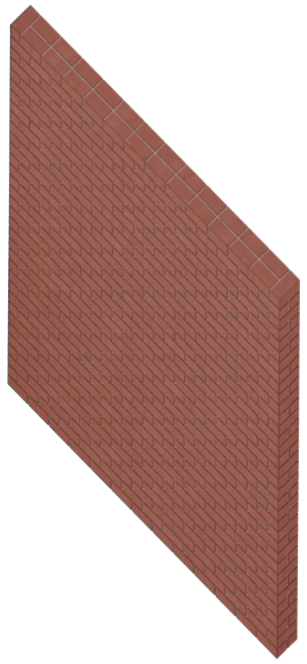
Although fired bricks can, in principle, be reused many times, recovery rates vary widely, particularly in places without regulations incentivising or mandating reuse. Bricks laid with lime mortar can often be cleaned and salvaged, while those bonded with cement mortar are difficult to extract without damage. Mechanical demolition typically destroys bricks or contaminates them with mortar, leading most demolition brick to be crushed for fill rather than reused structurally. Supply of clean reclaimed brick is therefore inconsistent and dependent on the process of deconstruction. Reuse also depends on labour-intensive dismantling, storage, and sorting.

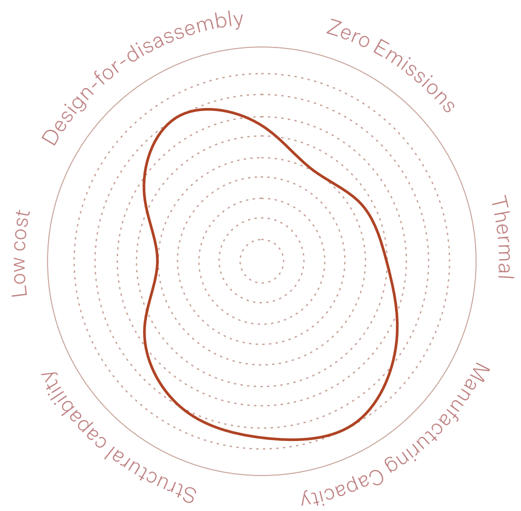
Durability remains high when detailing addresses moisture, salts, and foundation movement. Lime-based mortars, reversible tie systems, and planned deconstruction could substantially improve circular outcomes. Despite these constraints, fired clay brick remains a familiar and robust material suited to a wide range of architectural applications.

Typical brick production cycle



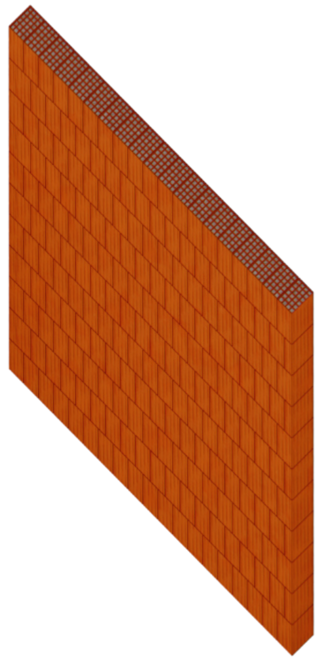
Clay-fired bricks

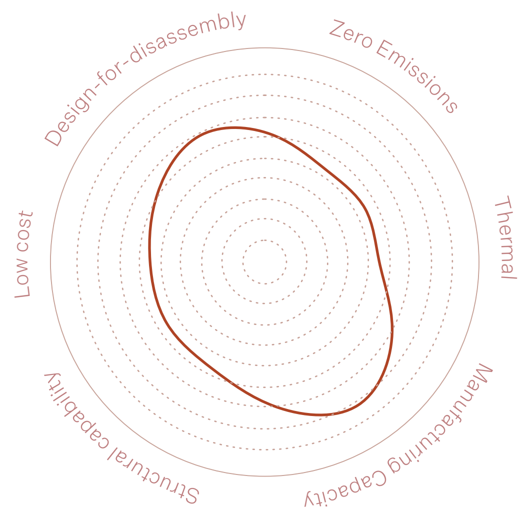




CLAY-FIRED BRICKS bricks are dense fired clay units used for load-bearing and non-load-bearing walls. They provide strength, durability, and excellent longevity, making them one of the most established construction materials. Good quality bricks, when maintained well, can last centuries. While clay-fired bricks are energy-intensive to produce, their modularity allows for reuse, giving them better circularity potential than most industrial composites.

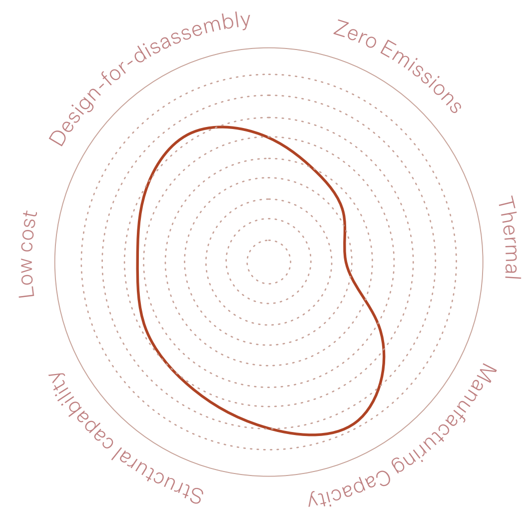
Hollow bricks





HOLLOW BRICKS contain cavities that reduce weight, material use, and improve insulation. They are easier to handle and quicker to lay than solid bricks, with moderate strength suitable for non-structural or medium-load-bearing applications. Although they require industrial firing, the reduced clay content and thermal efficiency give them a lower overall environmental impact.

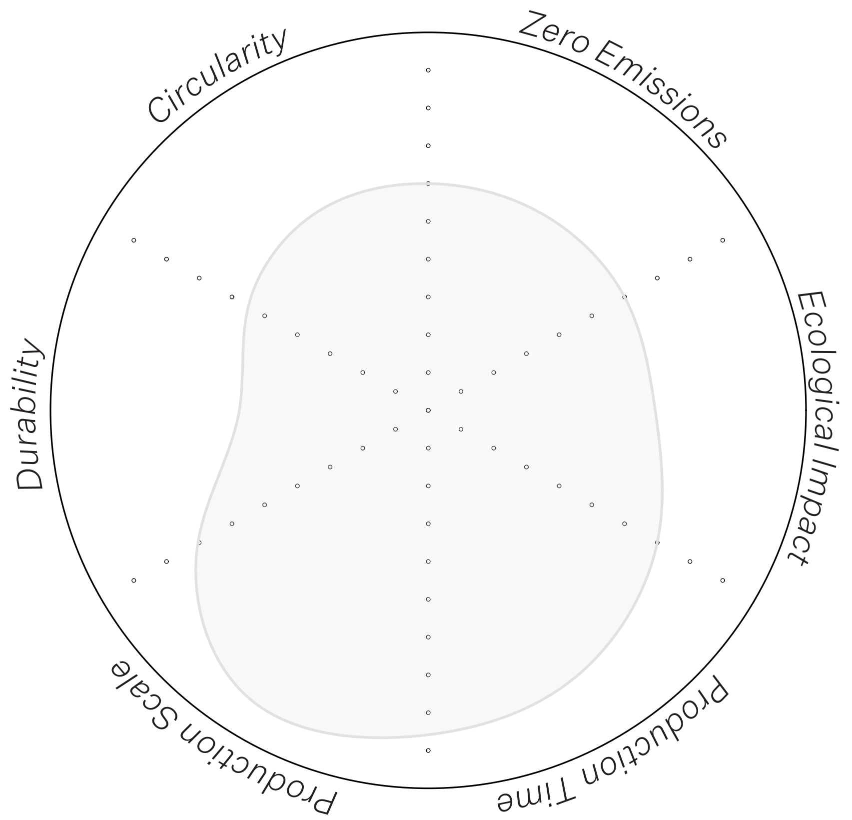
Tiles



TILES are durable, weather-resistant roofing units that provide excellent longevity, strong fire resistance, and good acoustic and thermal stability due to their mass. Tiles are laid in overlapping courses on battens, creating a ventilated roof system that manages moisture effectively. Individual tiles can easily be replaced supporting long-term maintenance. Their main environmental impact arises from the firing process, which consumes significant energy and contributes to embodied emissions. Tiles are brittle and can crack under impact, and their weight requires adequate structural support. Clean reuse is possible if tiles are removed carefully and remain undamaged.

PLASTER

Plaster

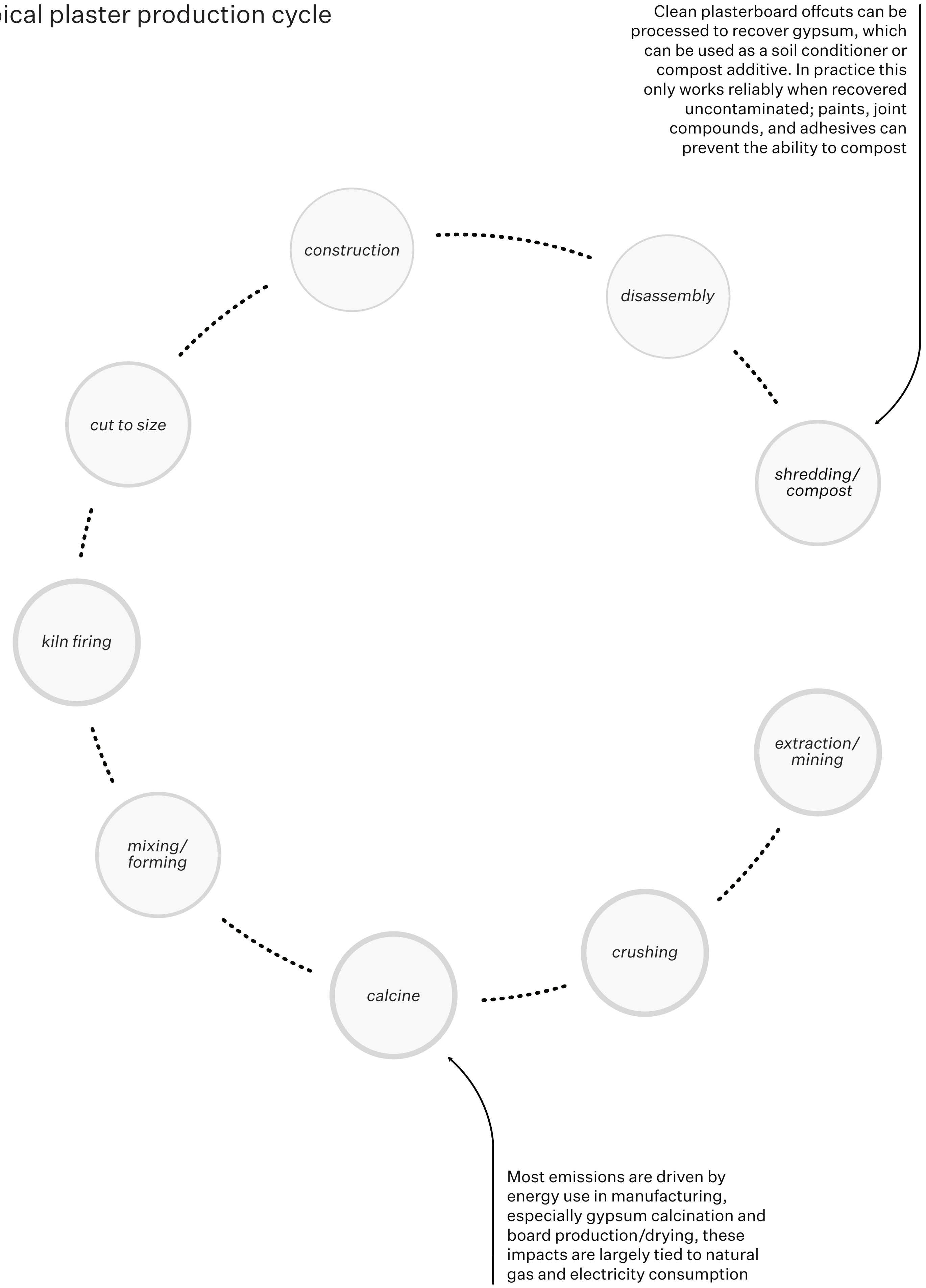


PLASTER and gypsum-based products are typically central to interior construction methods, providing lightweight, smooth finishes for walls, ceilings, and partitions. Modern plasterboard consists of a gypsum core faced with paper liners, offering good fire performance, acoustic moderation, and rapid installation. Production involves calcining natural or synthetic gypsum at moderate temperatures, giving plaster products lower embodied emissions than many cement-based alternatives. However, gypsum's moisture sensitivity and limited impact resistance influence its long-term durability and suitability for different interior conditions.

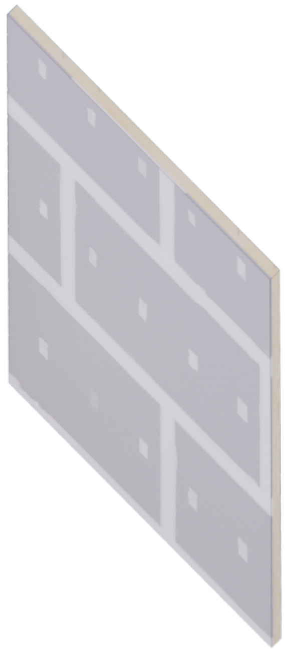
Although gypsum is technically recyclable, practical recovery is limited. Plasterboard is typically screwed or glued to frames, joined with compounds, and finished with paints or coatings, making separation of paper, plaster, and surface treatments difficult. Contamination from adhesives, jointing compounds, and fasteners often prevents clean recycling, leading most plasterboard waste to be downcycled or landfilled. Direct reuse of boards is rare due to edge damage, cutouts, and variable condition after removal. Moisture exposure can weaken the gypsum core, requiring replacement rather than repair in wet or poorly ventilated areas.

Plaster systems are used in internal partitions, ceilings, service cavities, and fire-rated assemblies. Improving circularity requires changes in installation practices, cleaner separation methods, and expanded waste collection infrastructure. Plaster is used almost as a default, due to its affordability, adaptability, and easy compatibility with legacy construction methods. Yet 'planet-aligned' alternatives exist: substitution, such as via clay; or simply through avoidance, by leaving, say, timber or brick interiors exposed.

Typical plaster production cycle



Plasterboard



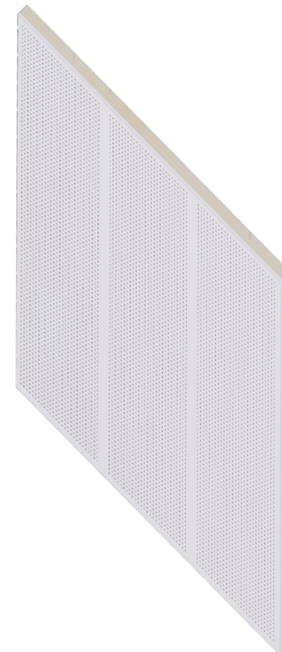
PLASTERBOARD is a factory-made lining panel consisting of a gypsum core faced with paper or fibre. It is lightweight, inexpensive, and easy to install, making it the default internal wall and ceiling lining. While recyclable under controlled conditions, adhesives, paints, and jointing compounds often complicate recovery. Its main advantages are cost, speed, and versatility rather than longevity or circular performance.

Wet plaster

WET PLASTER uses gypsum or lime mixed with water and applied directly to walls to create a smooth, continuous finish. They are labour-intensive but provide excellent acoustic and thermal moderation while allowing minor humidity exchange.

Materials / **Plaster** / Assemblages

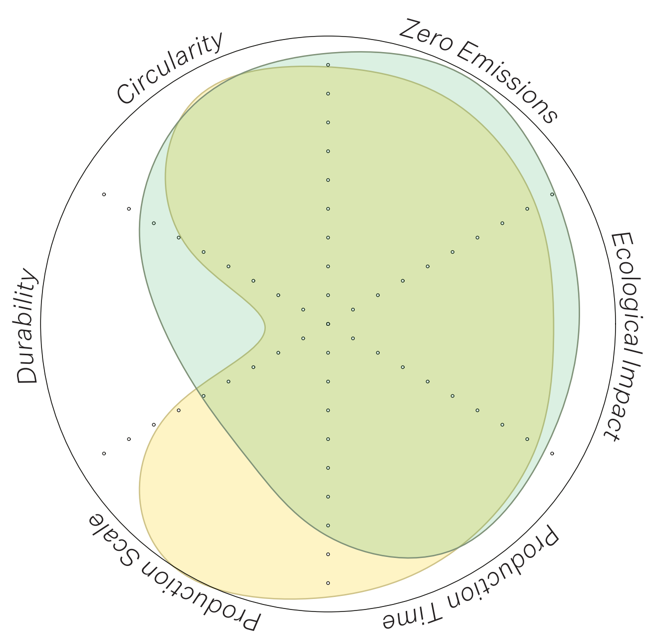
Performance-enhancing board



PERFORMANCE-ENHANCING BOARDS, such as acoustic, thermal, wet area, or fire-resistant plasterboard boards combine gypsum with fibres, foams, or mineral additives to enhance performance. They improve comfort and safety within buildings but introduce composite layers that are difficult to separate or recycle. These boards extend the functionality of gypsum products for specific applications, but their additional processing highlights the trade-off between performance gains and material circularity, relying on responsible specification and potential recovery schemes to close the loop.

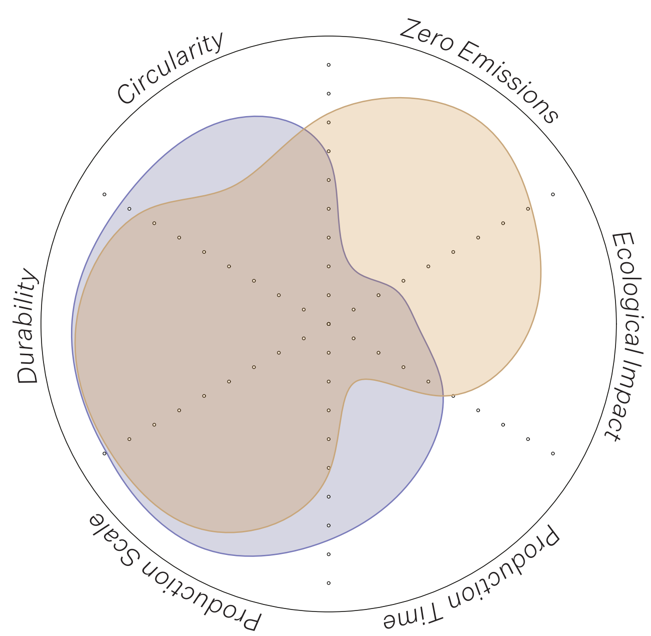
Example material comparisons

Hemp vs Straw



STRAW tends to score higher for production scale and production time because it is already produced in very large quantities in Australia as an agricultural by-product. **HEMP**, by comparison, requires dedicated cultivation and processing infrastructure, so its production scale and speed score lower in the current context. Hemp generally performs better on zero emissions and circularity due to its suitability as a rotation crop and its ability to deliver stable, mineralised or fibre-based products with good long-term durability. Straw's durability is more variable, reflecting its reliance on protective systems, whereas hemp-based materials can offer more consistent longevity. Overall, the comparison highlights straw as immediately abundant, and hemp as offering stronger low-emissions potential once supply chains mature.

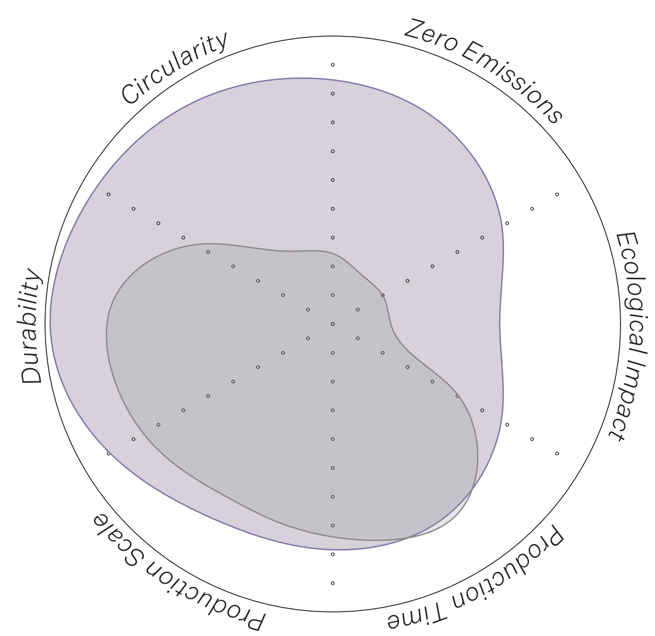
Timber vs Steel



TIMBER scores higher on zero emissions and circularity because it stores biogenic carbon and can be reused or reprocessed without high-temperature remanufacturing. **STEEL** performs well on durability and production scale, supported by a long-established industrial supply chain capable of producing large volumes of standardised sections. Production time is generally shorter and more predictable for steel due to its industrial fabrication processes, whereas timber is constrained by biological growth cycles and the availability of plantation resources. Timber's circularity depends on connection design and product type, while steel's relies more on recovery and reuse rather than recycling. The comparison shows timber as lower-emissions but resource-limited, and steel as durable and scalable, but highly damaging.

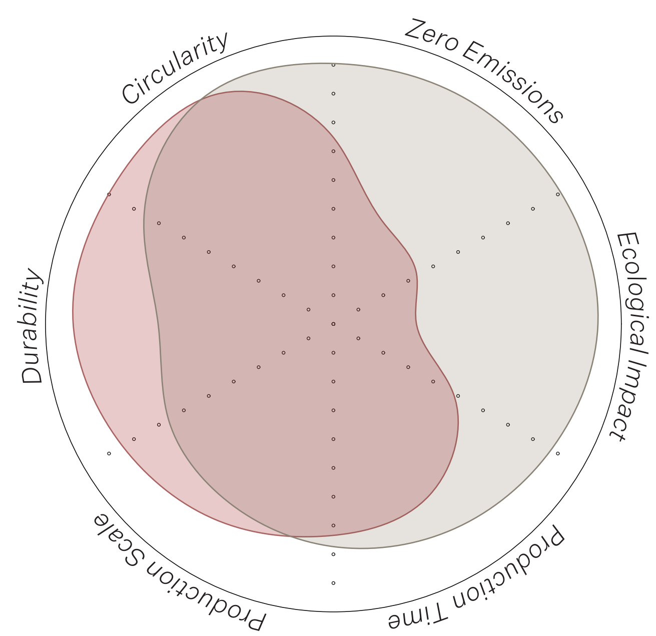
Materials / **Example comparisons**

Stone vs Concrete



STONE scores strongly on circularity and zero emissions as it is can typically be used largely in its natural state. It can also be dismantled and reused with minimal processing. **CONCRETE** performs better on production scale and production time due to its extensive global supply chain and rapid casting processes. Durability tends to favour stone, which can last for centuries with minimal degradation, whereas concrete durability depends heavily on mix design, cover depth, and exposure conditions. Concrete's emissions remain high as cement production is so energy- and carbon-intensive, as is its impact on ecosystems, while stone requires comparatively little processing. Overall, stone offers strong circular and low-emissions characteristics, while concrete's legacy 'installed base' offers speed and scalability.

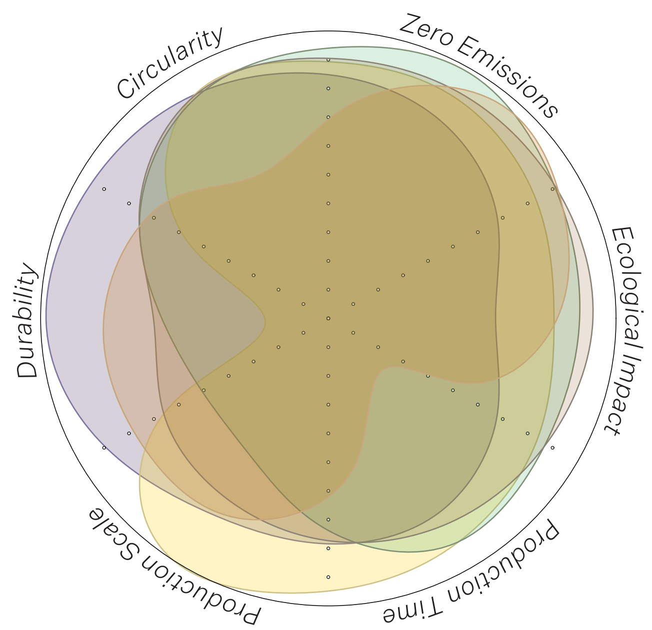
Earth vs Bricks



EARTH materials score very highly on zero emissions and circularity as they tend to involve minimally processed soils that can be reused or returned directly to the ground. Fired clay **BRICKS** score strongly on durability and production scale, reflecting their long lifespan and well-established kiln-based manufacturing industry. Production time is generally shorter for bricks, as industrial processes can operate continuously, whereas earth construction depends on soil suitability, labour, and curing conditions. Bricks score lower on zero emissions due to the energy required for firing, and their circularity depends on mortar choice and the feasibility of clean recovery. Earth performs well as a low-emissions, fully reusable material, while bricks offer robustness and industrial reliability.

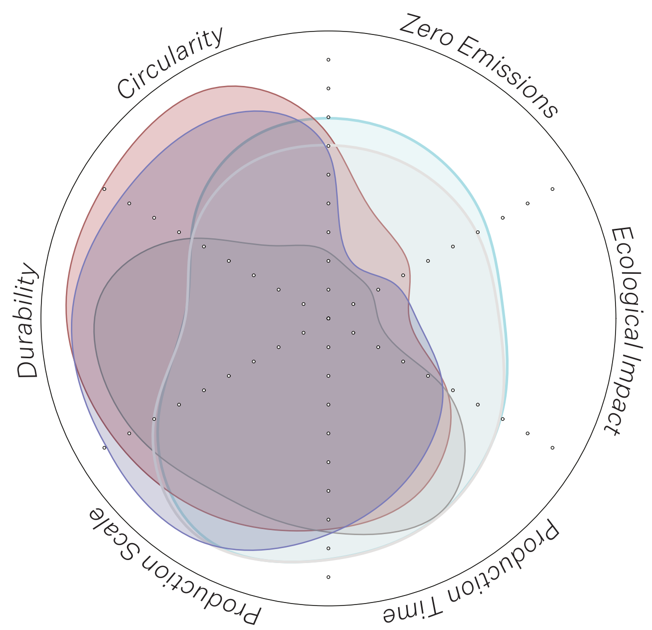
At-a-glance inferences

Planet-aligned materials



Simply by overlaying the profiles of the largely bio-based planet-aligned set of materials, it is immediately clear that this set effectively 'fills the circle' of the framework. Any building will comprise a combination of several materials (rather than just one), and any neighbourhood even more so. We might imagine that a diversity of circular buildings, produced from local regenerative sources, might balance out across all aspects of this framework. The *'shapes of the materials'* combine to cover circularity, emissions, ecological impact, durability, production time and scale, and as each material has particular capabilities, these might accrete in combination (noting that material assemblages have different shapes, as indicated). This also speaks to simpler forms of construction, via a deliberately limited local palette, in which material choice is akin to 'companion-planting', curation, or cooperation.

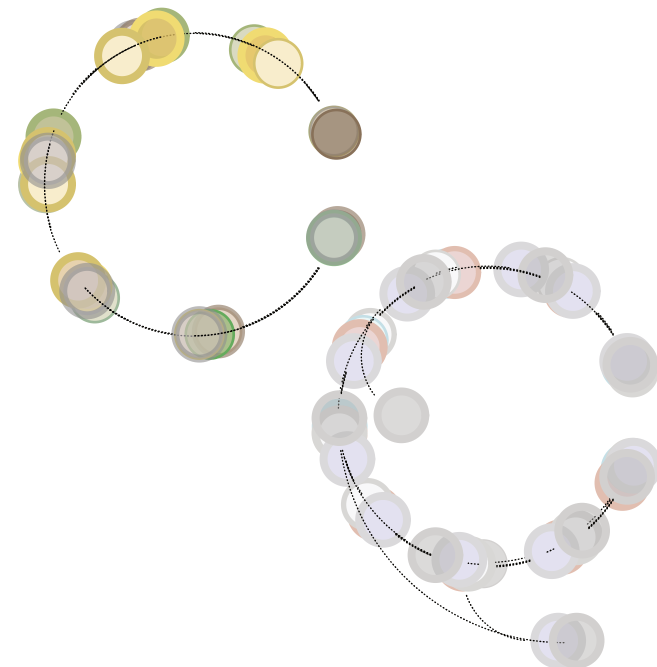
Industry-aligned materials



Continuing this deliberately high-level material comparison, the industry-aligned set clearly does not 'fill the circle'—noting again critiques of overly-quantified analysis (Petersen 2025). The industry might waste much time, finance, resource, and attention trying to push concrete and steel, say, towards the top of the circle. This diagram is not an invitation to do so—rather, these materials are inherently unlikely to be able to achieve *absolute sustainability* (Munch-Petersen and Beim, 2023), and better bio-based alternatives already exist.

> There is a natural limit to the planetary resources that can support sustained life. From this perspective, sustainability takes on an absolute quality: our solutions are either sustainable or they are not.
> Mossin et al (2023)

Assessing production cycles



The visualisations for material production also reveal, at least at high level, the relative complexity of industry-aligned material processing versus those of planet-aligned materials. Although these production processes have been simplified for this analysis and visualisation, they have been simplified equally at least. By overlaying and adjusting these visualisations of the production cycles, the planet-aligned materials appear to have simpler production cycles, with several fewer steps on average, than the typical industry set. Each of the lines connecting steps could be analysed and visualised in greater depth too, as they represent very different aspects of production—from growing to mining, local or global logistics, drying or firing, each with different speeds, values, and impacts. But even this high-level sketch suggests the potential of a simpler yet richer bio-based production process.

Assessing buildings

Of course, these comparative overlays could also apply to the material assemblages presented in this work. And as each building is ultimately a series of material choices overlaid and interwoven, these visualisations could also describe any building's overall positioning on circularity, at least as defined in this framework. This suggests each building might be able to be characterised, at least at this high level, by an image describing its performance—as if a *'kitemark'* or other such marque of quality of innovation in design. However, we are aware of the obvious dangers of such approaches being a distraction, noting that industry-led rating systems, like BREEAM, Green Star, and others, are yet to indicate that they can meaningfully produce system change in the built environment sector, at least regarding the scale and direction of the shift described here.

Green House
Blue House
Aqua House

Stone Demonstrator, London
Groupwork, Webb Yates, Arup, and Future Observatory (2025)

Stone building prototype located on a Earls Court Development site, London, standing three storeys tall, measuring 6.5m x 6.5m. Designed by architecture practice Groupwork with engineers Webb Yates and Arup, and funded by Future Observatory and the UKRI Arts and Humanities Research Council (AHRC). Open to the public, it embodies and describes an alternate way to build that reduces carbon emissions by approximately 70% compared to a reinforced concrete frame, and 90% compared to a steel frame.

The Circle prototypes

The **Commonwealth Experimental Building Station (CEBS)**, established in 1944, represents a significant Australian precedent for research-through-building. Emerging from a post-war context of material scarcity and housing need, CEBS developed full-scale housing experiments to test new materials, prefabrication systems, and construction standards. Its work demonstrated how state-supported prototyping could bridge research, industry, and public policy, producing not only technical data but also a cultural shift in how building materials and methods were understood. These houses were more than isolated tests; they were public exemplars that made new construction systems legible at a time of rapid technological and social change (Miller-Yeaman 2022).

In a similar spirit, this project proposes a series of prototypes as cultural and material research. They shift industry perception by translating experimental materials into built form, showing how non-standard systems can perform in real contexts. They also expose the complexities of making: where components meet; how materials behave; and what forms of labour, logistics, and infrastructure are needed to support new circular systems. This work is as much about feasibility as it is about identifying shortfalls in material supply, compliance, and regulation. Challenging dominant material paradigms inevitably places pressure on existing codes, and demonstrators can function both as proof of concept and as instruments for policy evolution. Strategic prototypes are 'built questions', helping flush out technical or cultural issues, generating learning whilst building momentum to move towards larger-scale system demonstrators for systemic change.(Hill and Melander 2025). Through building, ideas that remain abstract in diagrams or models are confronted with the practical realities of tolerances, moisture, sequencing, and failure. Contemporary innovation methods, such as mission-oriented innovation, also use this process of making to bring together multiple stakeholders—including politicians, policymakers, community, educators, and media, as much as industry and research—around these challenges (Mazzucato 2020, Hill 2022). Public-facing prototypes help shift the perception of buildings, creating a demand for innovative new (and old) material environments.

Several equivalent European projects are moving beyond the prototypes of individual buildings and exhibition projects, and into the system demonstrator stage of neighbourhood/district scale. For example, *The Erven* development, outside Amsterdam in Hoofddorp, will feature 500 homes composed in cross-laminated timber, with timber-frame walls insulated with straw and wood fibre, facades combining wood, reed, hemp fibre, lime and recycled aluminium, with roofs of reed and timber shingles and recycled concrete and gravel foundations. *Wood City* in Sickla, Stockholm, is the world's largest urban construction project in wood, at 250,000 square meters of mixed-use buildings. There are many more.

Australia currently has no equivalent projects of this scale and ambition. Transforming Circle's framework into simple but compelling prototypes could help demonstrate that such buildings—and their new practices, industries, economies, and material systems—are not only entirely possible, but desirable.

As part of this project, three demonstrator typologies were developed—the **Green House**, **Blue House**, and **Aqua House**—each testing a different material metabolism drawn from the Ellen MacArthur Foundation's (2021) distinction between biological and technical cycles.

The **Green House** explores grown materials, using straw–timber cassette panels as its primary

Stone Demonstrator, London Groupwork, Webb Yates, Arup, Future Observatory (2025)

envelope system. The choice of straw is deliberate: unlike hemp, which remains limited by processing infrastructure, straw is already produced at immense scale as an agricultural by-product in Australia. When paired with timber framing, straw cassettes offer high thermal performance with significantly reduced timber demand, illustrating how agricultural by-products can be incorporated into scalable, carbon-storing construction systems that return safely to the biosphere at end of life.

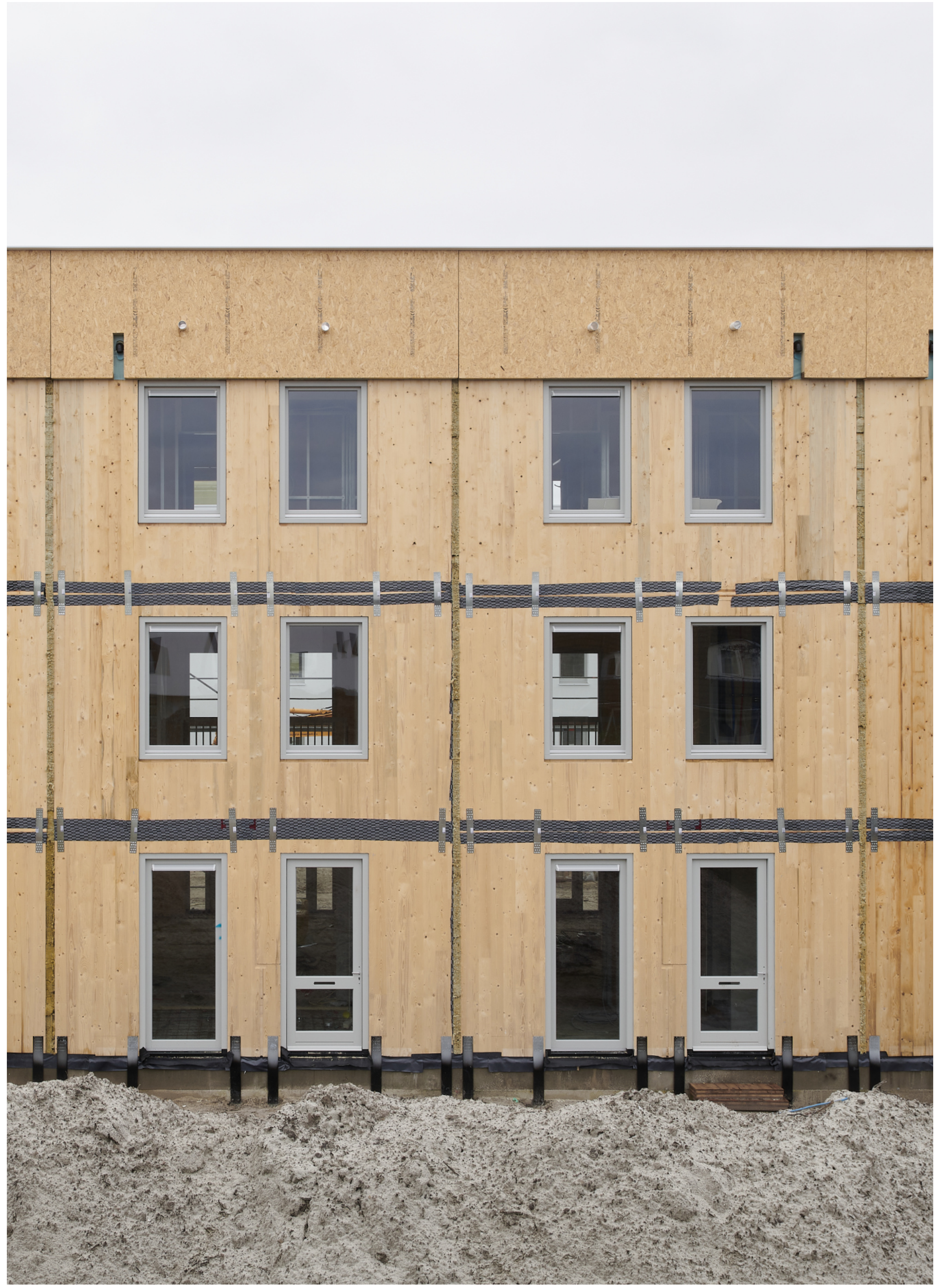
The **Blue House** addresses the technical cycle, where materials such as steel, brick, glass, and concrete should circulate through reuse and repair rather than demolition and downcycling. While a fully circular technical system would prioritise retrofitting existing buildings and deconstructing only when necessary, this demonstrator concentrates on an under-utilised opportunity in Australia: the reuse of precast concrete panels. Drawn from the vast stock of tilt-up industrial buildings likely to be redeveloped, these panels, currently rarely salvaged, are treated as high-value components rather than waste, demonstrating how existing materials can remain in construction loops without the energy- and water-intensive processes of crushing and re-casting.

The **Aqua House** operates as a hybrid, combining biological and technical principles through the use of tensioned structural stone. Stone is one of the most abundant and durable materials available, historically reused across centuries and requiring no chemical transformation, only quarrying and cutting. When paired with minimal steel tendons, stone can perform as beams, slabs, and compression members with dramatically lower embodied emissions than concrete. Its compatibility with timber and CLT systems further broadens its application. Tensioned stone provides high structural performance, excellent fire resistance, and reusability, positioning it as a compelling low-emissions alternative to concrete (Future Observatory, 2025).

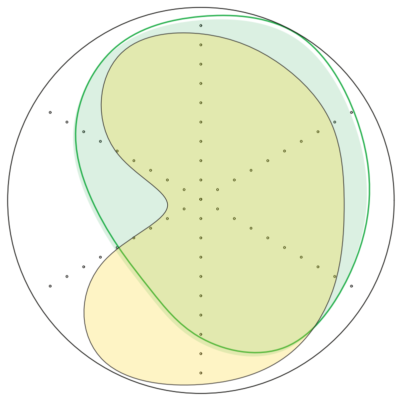
Each prototype, sketched by André Bonnice over the following pages, represents a different but complementary approach within a broader material ecology. None offers a singular solution. Instead, they demonstrate that a circular future will rely on a diversity of materials and methods, agricultural by-products, stone, reuse, and responsibly sourced timber, rather than dependence on any single industry or technology. Timber will remain central to low-emissions construction in Australia, but it is a finite resource that must be used strategically. The next material transition must therefore balance biogenic growth, geological materials, demographic shifts, and industrial recirculation to meet future demand while staying within our ecosystems' limits. More broadly, moving beyond circularity towards *absolute sustainability* (Munch-Petersen and Beim 2023), that demand must also be shaped, as indicated by the range of strategies outlined in the Australian Reduction Roadmap (Crawford et al 2025), such that alternate possible futures emerge, each capable of thriving within planetary boundaries.

Taken together, these three prototypes are Project Circle's framework in tangible form: not complete answers, but instruments for learning, prompts for discussion and critique, technical and ecological testbeds, and open platforms for asking questions in public. Making them would require invention in design, sourcing, assembly, logistics, and performance, yet doing so would help build the confidence, capacity, literacy, and desire to support a circular construction transformation in Australia.

Garden with housing, Amersfoort Studio Nauta (2023)
Designed by Studio Nauta, 40 rowhouses for rent, with shared garden. Constructed with cross-laminated timber. Engineering by Treetek, landscape by Le Far West, contractor is Karbouw. Pictured during construction.



Green House



Hemp and Straw

The Green House explores how agricultural by-products can form the basis of a new material culture for housing in Australia. It proposes a construction system made from prefabricated straw–timber cassette panels, combining compressed straw insulation with a light timber frame to create a vapour-open, breathable wall system with high thermal performance and low embodied emissions. The choice of straw is both strategic and immediate. Australia produces one of the largest per-capita outputs of cereal crops in the world, generating an estimated 25 million tonnes of straw residue annually. Redirecting even 5% of this surplus, around 800,000 tonnes, could supply enough material to construct more than 100,000 homes each year, with each 140 m² dwelling requiring only 7–8 tonnes of straw.

Straw was selected over hemp because it is readily available and already embedded in existing agricultural systems, allowing its use in construction to be incorporated immediately. As previously observed, hemp holds similar potential, with multiple applications across hempcrete, hemp blocks, and cassette systems, but Australia currently lacks the processing infrastructure and supply chain needed for large-scale deployment. These systems can, however, be integrated as soon as the necessary facilities, such as decortication and binder production, are established.

The use of timber cassettes reduces total timber consumption while providing the structural capacity and precision that straw alone cannot achieve. Prefabrication enables consistent quality, rapid on-site assembly, and low material waste, opening opportunities for regional manufacturing tied to cropping regions. Challenges remain: detailing for local moisture and fire performance conditions, and the absence of certification frameworks for bio-based systems, currently limit adoption in Australia. Yet these are precisely the issues that prototyping seeks to address, helping bridge material potential with regulatory and cultural acceptance.

The Green House is not presented as a singular solution but as evidence of what can be achieved now with materials already in circulation. By coupling an underused agricultural by-product with timber, it demonstrates how construction can begin to align with ecological cycles, while establishing the foundation for integrating hemp and other regenerative materials as their supporting infrastructure develops.

Australia produces tens of millions of tonnes of cereal straw each year as an agricultural residue. Redirecting even a small proportion of this material has outsized potential for construction. If just five percent of current straw production were diverted into building applications, we calculate that it would yield roughly 1.5 million tonnes of usable fibre annually, enough to supply material for approximately 112,000 straw-based homes per year.

This figure is comparable to the scale of Australia's yearly housing starts. It demonstrates that bioregional, agricultural by-products already exist at a magnitude capable of supporting mainstream construction, and that regenerative materials need not be framed as marginal or boutique. Effectively,

Hyllie building, Malmö Kaminsky Arkitektur (2026)
12-storey mixed tenure housing, with exterior envelope of EcoCocon straw panels protected with timber cladding, sprung off a mass timber core. Pictured during construction, December 2025

these agricultural systems are a 'pre-installed' infrastructure, which could be partially diverted towards this potentially higher-value outcome for farmers and industry, as well as solving a problem for the construction sector.

Adjusting the trajectory of an existing infrastructure is described as a 'lever' strategy in the Swedish mission-oriented innovation approach, detailed in Hill (2020), reinforcing the suggestion of innovation missions for circular construction.

Australia's long-standing capacity with cereal straw currently represents an under-utilised national resource which might be mobilised to reduce embodied emissions, support rural economies, and build capacity for circular material systems. Of course, for *regenerative* circular systems—in which buildings improve our soil rather than diminish it, as a systemic impact of construction, for example—the agricultural practices which produce this straw must also be regenerative, just as buildings must be designed for disassembly and without introducing contaminants to natural building elements. This represents a linked challenge for both industrialised agricultural and construction sectors.

Yet our overall challenge remains the same: to recognise that these sectors have been artificially separated, and that they might be re-integrated, by effectively seeing that agriculture and architecture could be the same sector, just as previously mining and architecture has been. We must solve these challenges simultaneously via shared integrated outcomes.

Diverting just 5% of Australia's annual straw production could supply enough straw to build 110,000 homes every year.

Australia produces 30 million metric tons of straw per year on average

43% of straw produced is used on the farm

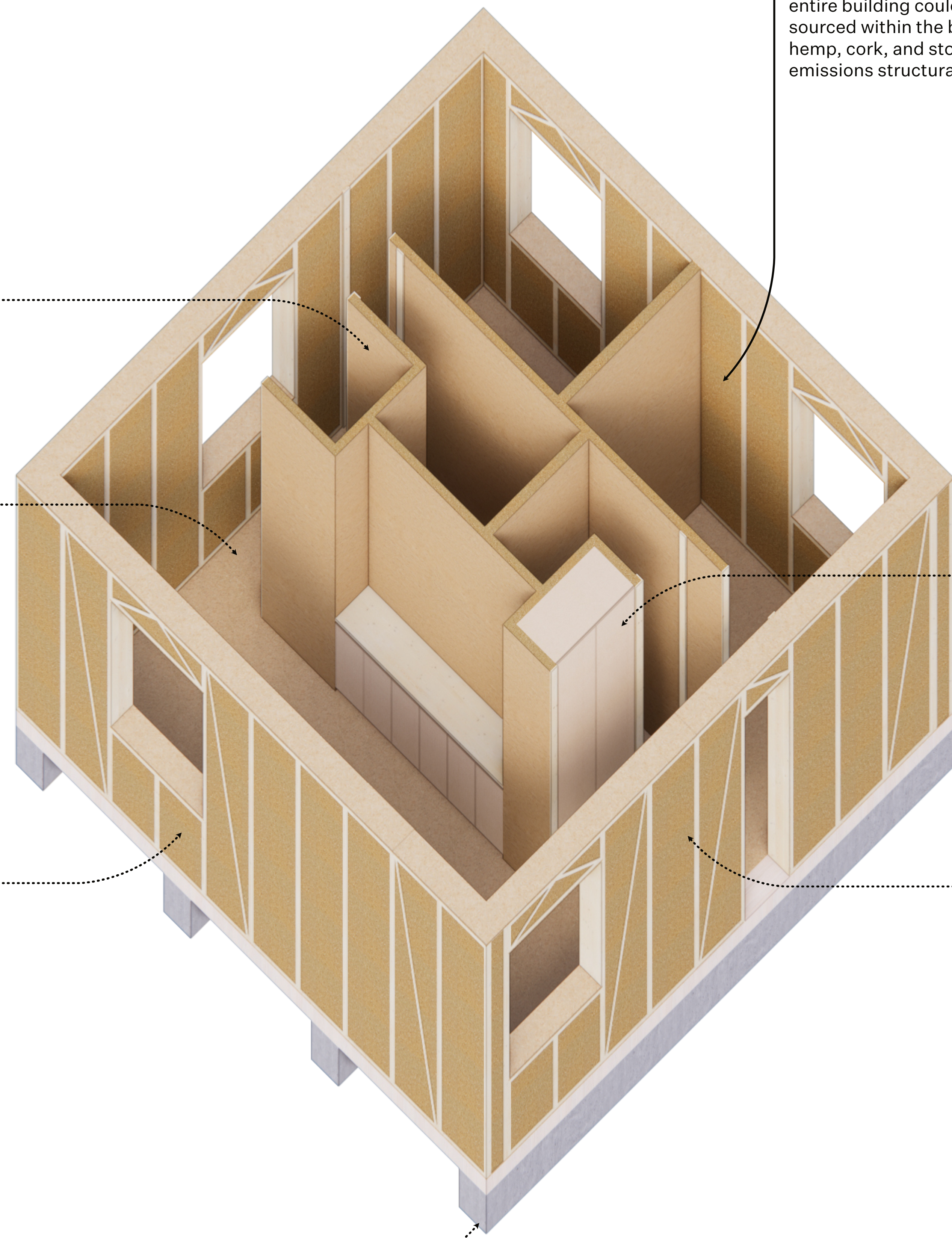
57% of straw produced is sold off the farm

What if **5%** of this was used for construction materials?

Feldballe School, Rønde Henning Larsen (2022)
School extension featuring EcoCocon's wall system of compressed straw in wooden cassettes as the primary design and building element, allowing for precise bio-based construction. The straw panels are covered in clay and the structure's roof is solely of timber. The ventilation system filters are made of eelgrass, an abundant locally-sourced seaweed, which also helps reduce ambient noise.

Single storey

Diagram of a single-storey, 65 m² two-bedroom dwelling demonstrating how an entire building could be formed from materials sourced within the biosphere, straw, timber, hemp, cork, and stone, assembled into a low emissions structural system.



Internal partitions formed from compressed straw panels, offering rigid, non-structural walls with good acoustic moderation, humidity buffering, and low embodied emissions.

Timber cassette floor system with straw infill delivers lightweight structural spanning, strong acoustic separation, and stable thermal performance, finished internally with a cork floor for comfort and additional insulation.

Joinery and cabinetry constructed from hempboard, providing a low-toxicity, fibre-based alternative to MDF with good surface stability and interior durability.

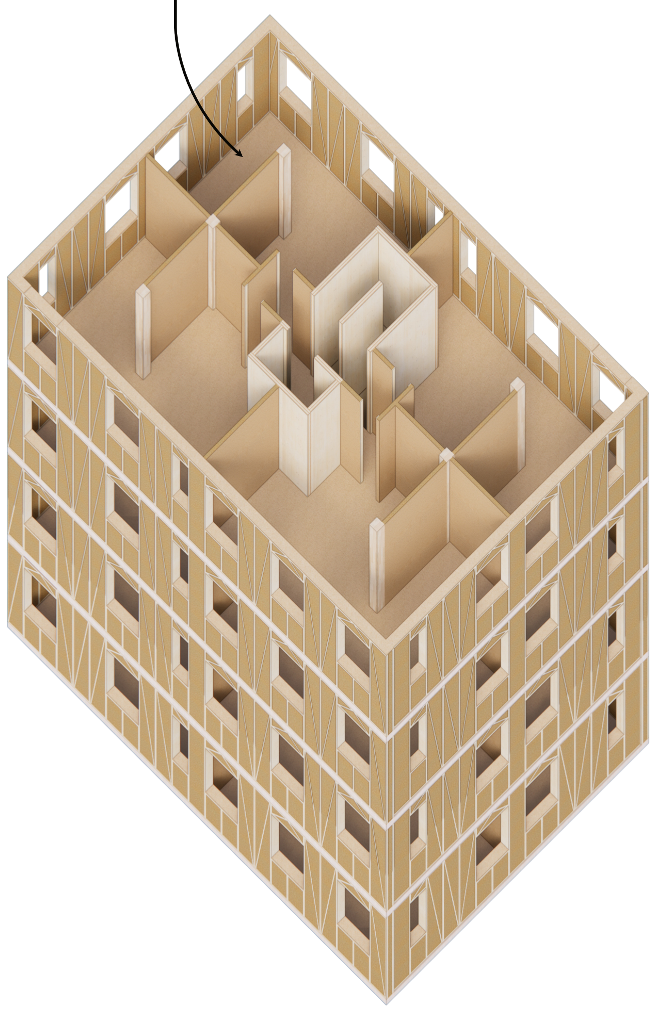
Straw–timber cassette walls act as the primary structure, combining a light timber frame with compressed straw insulation to provide load-bearing capacity, high thermal performance, and vapour-open enclosure.

External finishes may include timber boards, timber shingles, cork spray, or lime/earth renders, each contributing weather protection while maintaining vapour permeability and allowing the wall system to perform thermally.

Stone footings and foundations provide a durable, low-emissions base, supporting full material recoverability and strong moisture protection at ground level.

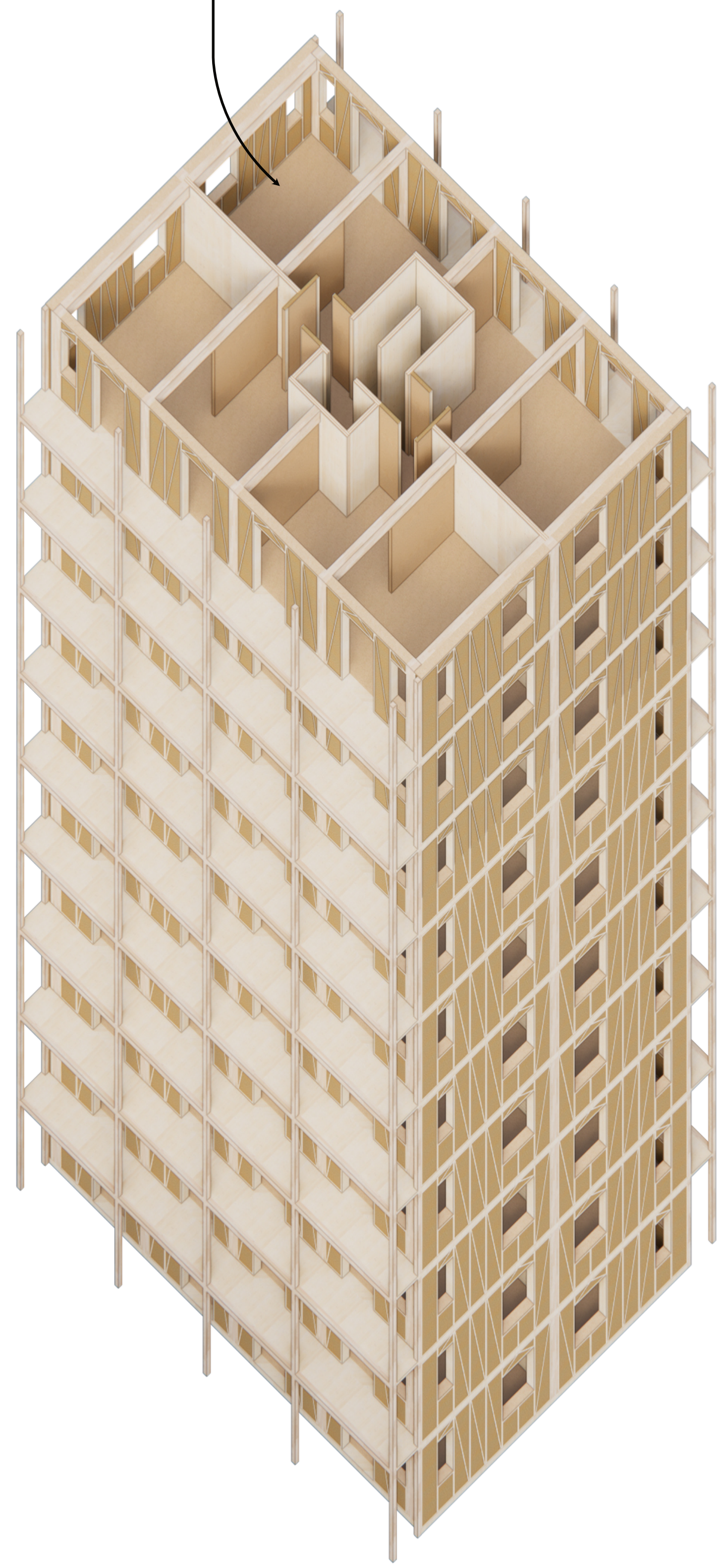
4–6 storey

This diagram illustrates how the straw–timber cassette system can be extended into mid-rise buildings of approximately 4–6 storeys, with the cassettes acting as the primary structural walls. The system uses timber framing integrated into each cassette, allowing vertical load paths, and lateral stability to be achieved without relying on additional structural materials. Compressed straw provides continuous thermal performance and acoustic control. Floor plates can be formed from timber cassettes or lightweight timber joist systems.

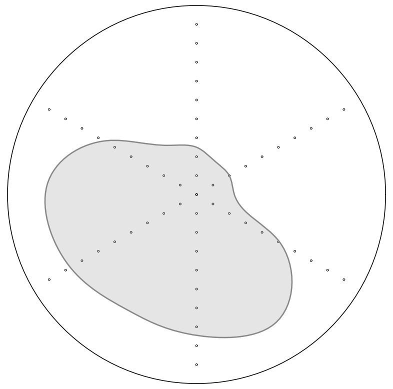


12–18 storey

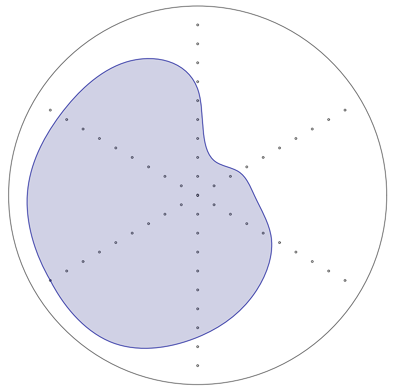
This diagram shows a hybrid configuration in which a mass-timber frame, using CLT cores, glulam columns, and timber floor systems, provides the primary structure for buildings up to 12–18 storeys. In this system, straw–timber cassettes no longer carry structural loads but serve as high-performance infill panels that form the thermal envelope.



Blue House



Concrete



Steel

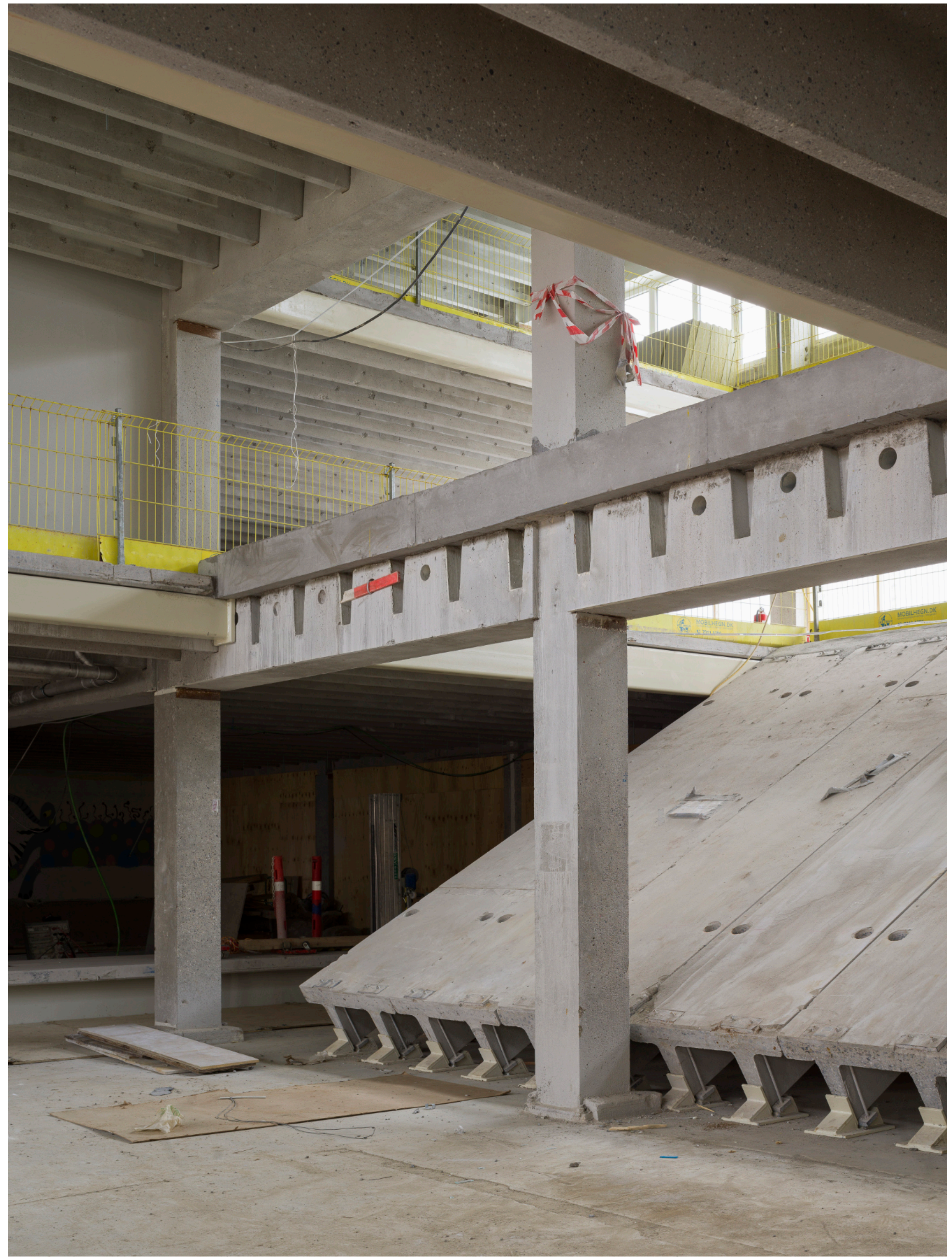
The Blue House examines how materials circulating within the technosphere, the domain of industrial, non-biological resources, can be kept at their highest value for as long as possible. In the broader sense, a *blue-cycle* approach includes steel, brick, concrete, glass, and other construction materials that can be reused, remanufactured, or reassembled without returning to energy-intensive melting, firing, or crushing processes. District-scale projects in Europe, such as the redevelopment of Varvsstaden in Malmö, show how systematic salvage, careful deconstruction, and coordinated logistics can create material banks that supply new buildings with components recovered from existing ones (Bonnice and Jankovic 2024).

The focus is on the reuse of precast concrete panels. In the coming decades, vast networks of tilt-up industrial estates and business parks will be redeveloped. These buildings contain thousands of standardised concrete panels that are typically demolished and crushed into low-grade aggregate, a process that is energy-intensive, water-intensive, and discards the structural value and embodied emissions within the panels. International examples demonstrate that retaining components whole, rather than reducing them to raw material, offers the greatest environmental and economic benefit.

The Blue House proposes a dwelling designed around reclaimed precast elements. Instead of beginning with a blank plan and new materials, the process starts with the dimensions, openings, and tolerances of panels sourced from deconstructed industrial buildings. Layout, structure, and facade expression emerge from what is already available, transforming demolition into a sourcing phase rather than an endpoint. This approach raises critical practical questions: *How might panels be catalogued and tested at the point of deconstruction? What kinds of reversible fixings and junctions allow for varied sizes? How can certification and compliance accommodate reused structural components? How much storage might be needed in local material banks during reconstruction? And how can design adapt to the irregular 'supply' released by staggered redevelopment across industrial precincts?*

The Blue House is a framework for revaluing and recirculating precast concrete within the technosphere. By concentrating on precast elements, a material stream whose reuse potential in Australia remains almost entirely untapped, the prototype demonstrates how the life of concrete can be extended rather than reset. Closing the loop for precast means retaining panels as panels, preserving the energy, labour, and precision already embedded within them, and redirecting demolition from a destructive process toward one of recovery and reassembly. In doing so, the Blue House illustrates how technical materials can remain in active circulation rather than prematurely return to energy-intensive downcycling, supporting a construction culture that treats the built environment as a long-term material commons rather than a linear process of extraction and waste.

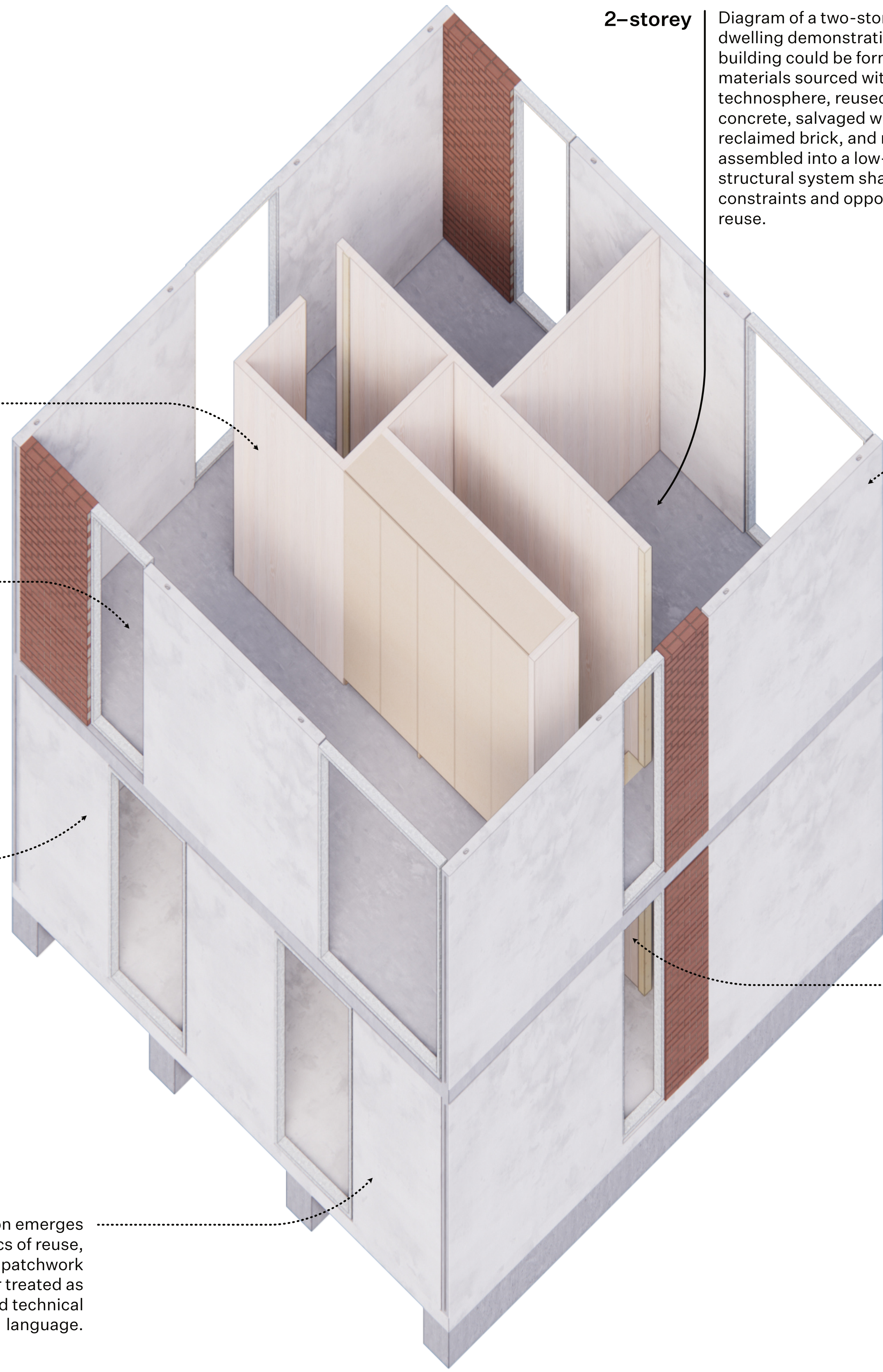
Thoravej 29, Copenhagen Pihlmann Architects (2025)
This 1967 concrete building has been retrofitted by Pihlmann Architects, with every component of the existing building saved and repurposed (even those elements typically considered insignificant). During transformation, the building was thought of as its own materials bank, allowing it to "recycle itself", with floor slabs tilted into staircases, façade elements reworked into pavement, fittings transformed into furniture.



Prototypes / **Blue House** / System design

2–storey

Diagram of a two-storey, 130 m² dwelling demonstrating how an entire building could be formed from materials sourced within the technosphere, reused precast concrete, salvaged windows, reclaimed brick, and recycled timber, assembled into a low-emissions structural system shaped by the constraints and opportunities of reuse.



Internal walls constructed from salvaged timber framing and lining boards, allowing lightweight, adaptable partitions within the heavy concrete shell.

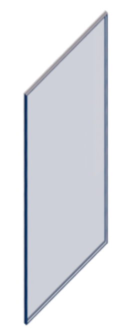
Flooring from reclaimed timber, laid over battens or directly laid onto concrete.

Primary structure formed from repurposed precast concrete panels, sourced from demolition sites and industrial surplus.

Architectural expression emerges from the logistics of reuse, mismatched tolerances, patchwork infill, and visible repair treated as part of the aesthetic and technical language.

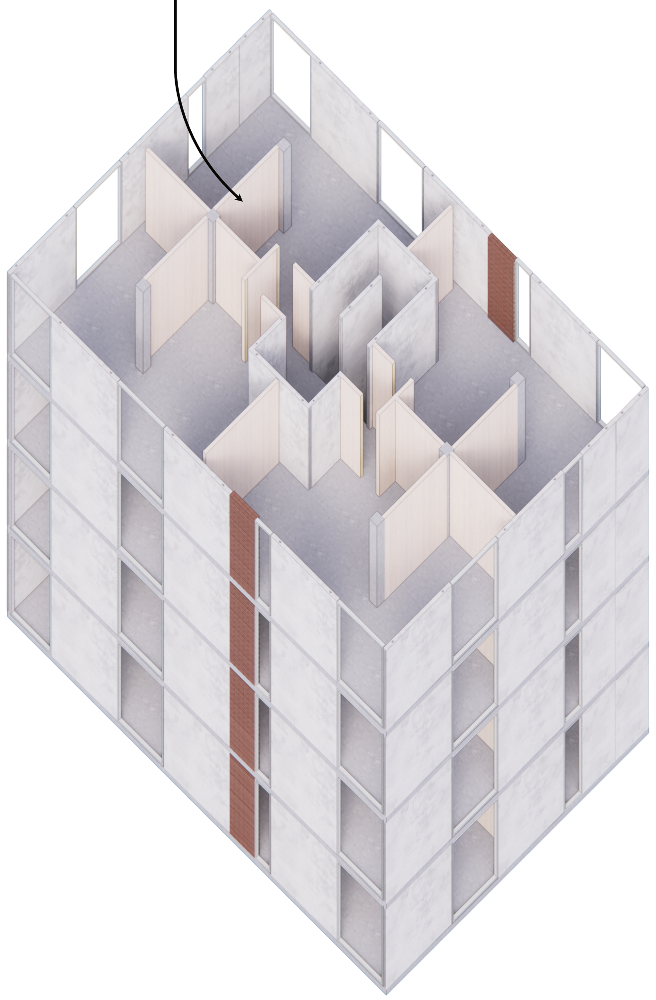
Building geometry is derived from the existing dimensions of salvaged panels and windows; plan and elevation are set out to match available sizes rather than standardised modules

Reclaimed windows and doors inserted into existing openings or cut-outs where feasible; design prioritises reusing full units over resizing.

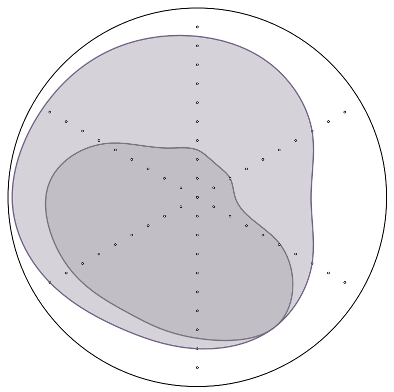


4–6 storey

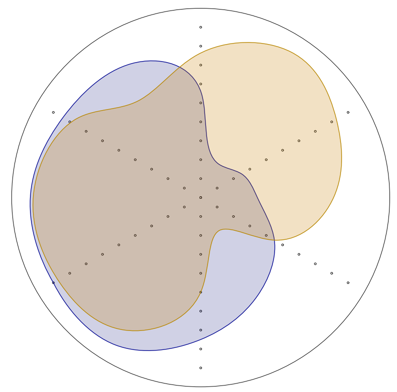
This diagram illustrates how a reused-precast system could be extended into mid-rise buildings of approximately 4–6 storeys, using salvaged concrete panels as the primary structural walls and façade elements. The approach relies on assessing and re-certifying each panel's structural capacity, meaning scalability is highly dependent on material condition and load-bearing performance. Where panels can be stacked safely, vertical load paths are achieved through existing reinforcement, supplemented by engineered connections and external bracing where required. Reclaimed brick or blockwork can be used for infill and stability, while recycled timber systems form internal partitions and floor plates.



Aqua House



Stone vs Concrete



Timber vs Steel

The Aqua House focuses on structural, tensioned stone as a hybrid material system that bridges the biological and technical cycles. Stone is arguably the most durable construction material in human history; entire cities, such as Athens, Rome and large chunks of Paris, have been built on its longevity. Across centuries, stone has been inherently circular: blocks were lifted, re-cut, and reused as buildings were adapted or rebuilt, long before the language of 'circularity' existed. Unlike concrete or steel, stone does not need to be fired, melted, or chemically transformed; the material we need already exists in geological abundance.

Contemporary examples show how post-tensioned stone can replace reinforced concrete in many structural applications. By drilling slender ducts through stone blocks and applying high-strength tendons, stone can act as beams, slabs, columns, and frames with only a fraction of concrete's embodied emissions. The steel introduces a technical component, bringing stone partly into the 'blue' cycle, but the mass remains a predominantly 'green' material that is reusable when designed for disassembly. Fire testing shows that tensioned stone performs significantly better than reinforced concrete, maintaining integrity without explosive spalling due to its minimal water content.

Recent demonstrators, including research exhibited by the Design Museum's Future Observatory in London, highlight how stone can operate as a hybrid, multi-system material, capable of forming slabs without concrete, spanning as post-tensioned beams and lintels, or working in tandem with timber and CLT. These studies show that stone can be used singularly or paired with CLT cores or floor plates to create viable alternatives to conventional concrete systems.

Unlike timber, whose supply depends on decades of growth and often monocultural forestry, stone can be produced from a relatively compact, controlled footprint. While still extractive, stone sits at the lower-impact end of the spectrum: inert, stable, and free from the toxic leaching or industrial by-products associated with many mined materials.

Australia already has much of the quarrying and fabrication infrastructure required for stone construction. Unlike many bio-based materials, which need new processing and certification systems, stone can be scaled through existing industries. Scaling structural stone is also increasingly feasible through advanced manufacturing, including CNC cutting, robotic handling, and precision drilling. These approaches make stone predictable, testable, and increasingly code-compliant.

As a hybrid, the Aqua House complements timber, agricultural by-products, and reused industrial components. Stone offers durability, fire resistance, reusability, and exceptional longevity. By incorporating it into a contemporary structural logic, the Aqua House demonstrates how one of the world's oldest materials can be reactivated as a circular, low-emissions alternative to concrete.

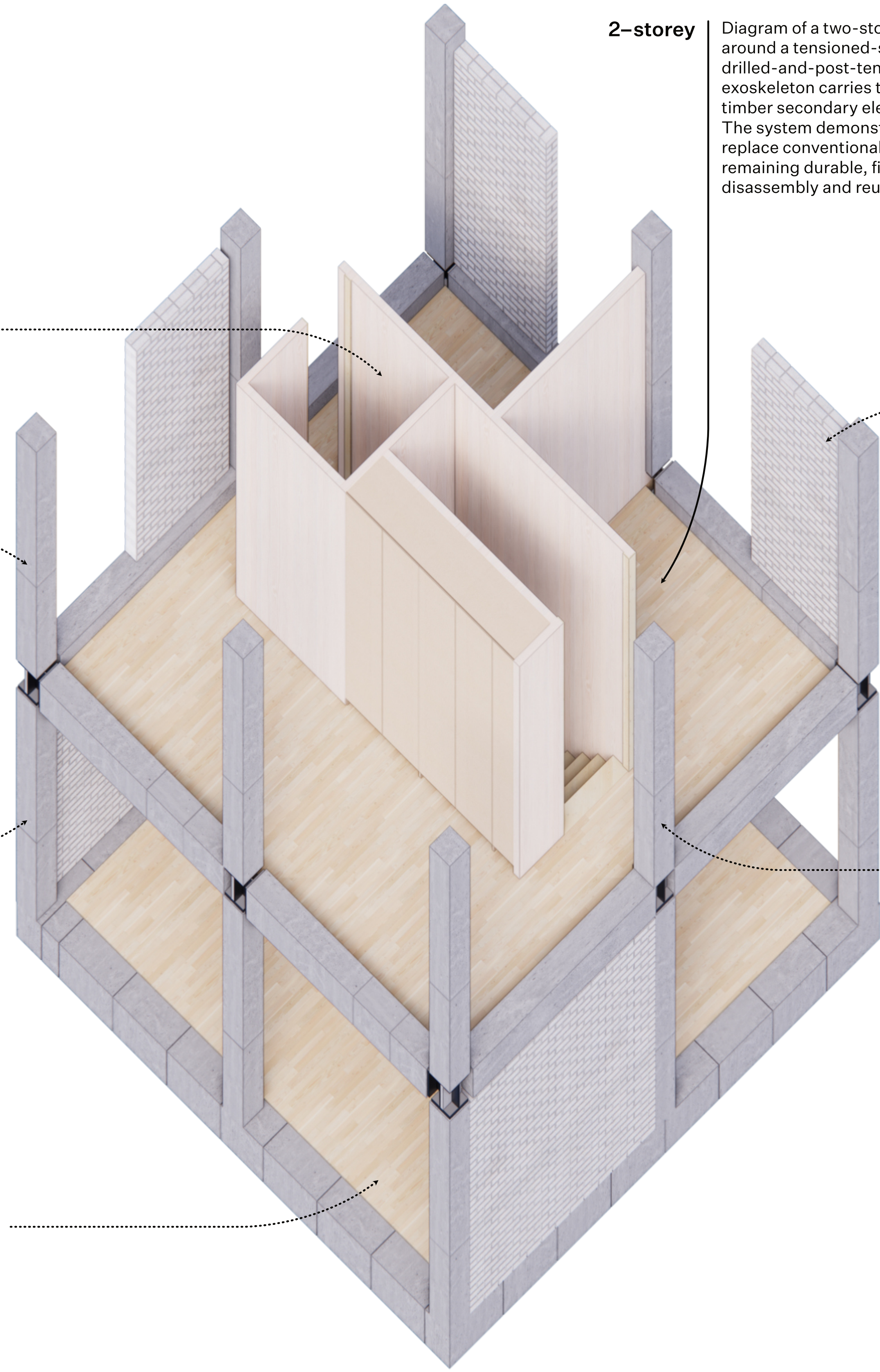
Stone Demonstrator, London Groupwork, Webb Yates, Arup, and Future Observatory (2025)

Joinery, cabinetry, and internal linings can be made from timber or hemp-based materials mirroring the bio-based interior strategy of the Green House.

System organised around a modular, repeatable stone grid, with posts, beams, CLT slabs, and infill units working as interchangeable components.

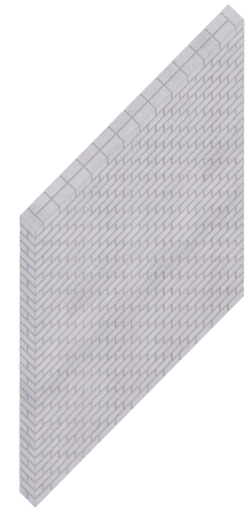
Primary structure formed from tensioned structural stone posts and beams, using steel tendons to compress stone elements and create a high-performance frame.

Floor plates constructed from CLT panels spanning between pre-tensioned stone beams



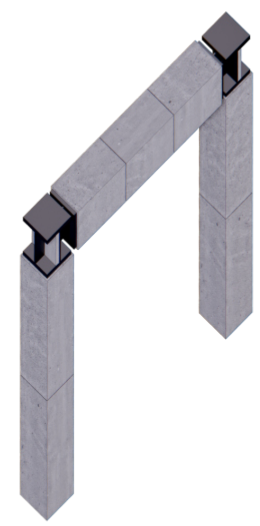
2–storey

Diagram of a two-storey, 130 m² dwelling organised around a tensioned-stone primary structure: a drilled-and-post-tensioned stone frame/ exoskeleton carries the main loads, with light timber secondary elements forming floors and roof. The system demonstrates how structural stone can replace conventional concrete framing while remaining durable, fire-resilient, and designed for disassembly and reuse.



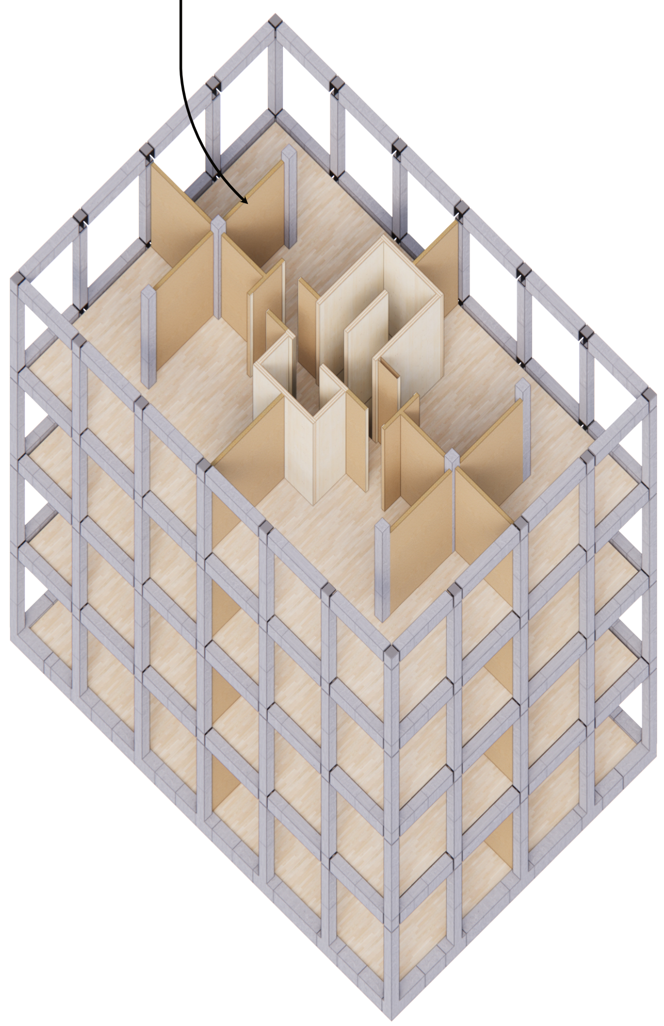
Infill walls built from stone bricks, providing mass, thermal stability, and a way to accommodate dimensional variations in the structural grid.

Windows and doors made from reclaimed or low-impact timber joinery, fitted to the fixed openings of the stone frame.



4–6 storey

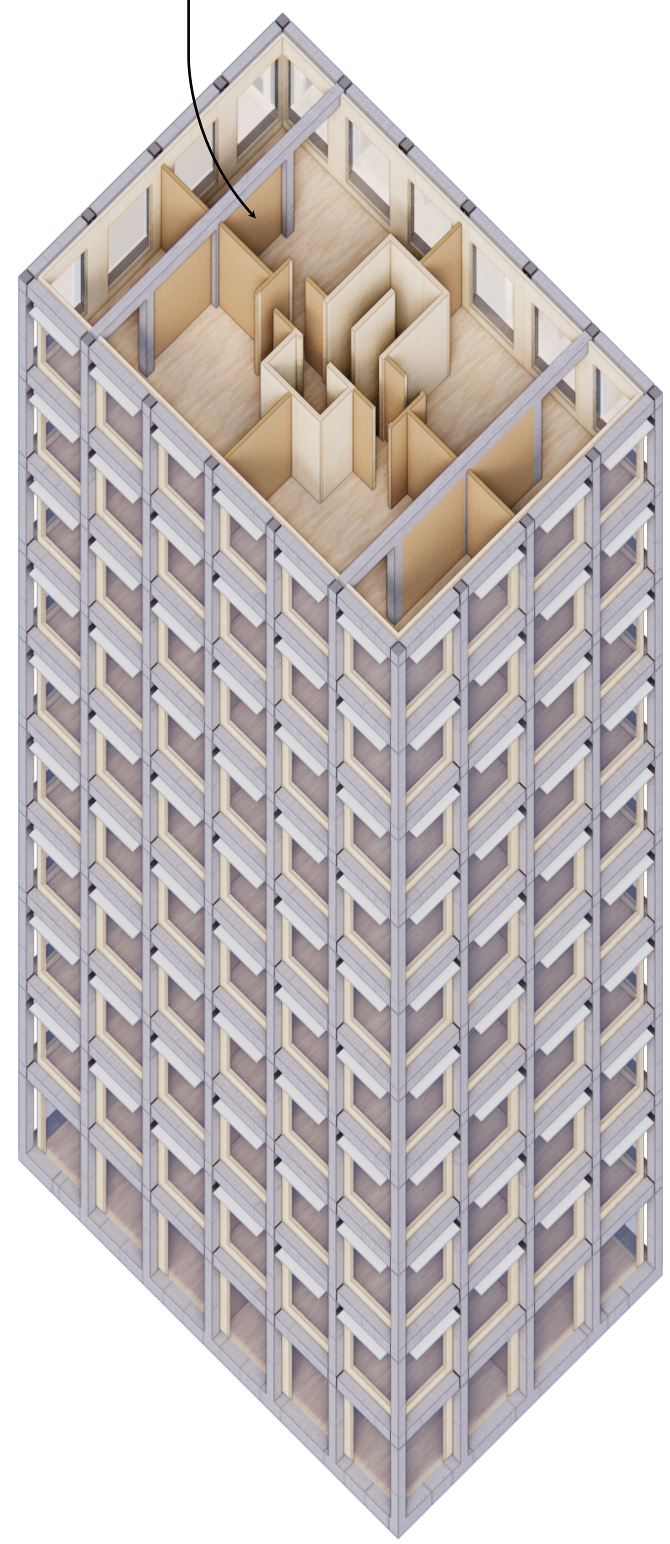
This diagram illustrates a pre-tensioned stone exoskeleton scaled for mid-rise buildings at 4–6 storeys. Stone blocks are drilled and threaded with steel tendons, then tightened so the post-and-beam frame works primarily in compression. Beams and columns are prefabricated, assembled and locked through tensioning. Light timber secondary elements (joists/cassettes) span between stone members to form floor plates while reducing the overall weight of the structure.



Prototypes / **Aqua House** / System design

10–18 storey

This diagram shows the same tensioned-stone exoskeleton scaled up for taller buildings in the 10–18 storey range, demonstrating the system's scalability. As height increases, stability is strengthened by pairing the exoskeleton with an internal systems, typically via a CLT core. Floors remain light timber secondary structures, spanning between the stone frame and core.



Conclusion

> To build is also to destroy.
> Charlotte Malterre-Barthes (2025)

What would it mean to say that '*to build is also to grow*'? Or to regenerate? That a building might make our shared soils healthier, our air and water cleaner, as an outcome of its construction? What if building could be closer to farming than mining, architecture closer to agriculture? How many buildings could be grown locally? How many do we actually need? How do we stop using more resources to try to solve a resource crisis? Can industry innovate without volume? How do we design for care, with what kind of practice model? What kind of relationships, what kind of contracts? How might maintenance become care, cost become investment? What new models of value, and different forms of growth, are created within a regenerative built environment? What new jobs, trades, and practices? How can architecture shift from designing objects to designing systems, from simply materialising spaces to spatialising materials?

These and many other questions arise from this project. Pursuing them by making the prototypes sketched here, each an embodiment of regenerative material flows and cultures, would allow us to reveal, describe, and demonstrate possible futures for construction. The research, analysis, discussions, and examples presented indicate the rich potential in this vivid alternative palette of circular materials, produced from local and regional sources, to be used in place of the default 'industry-aligned' set of materials currently locked in place.

Even in this first phase, the Circle framework makes immediately clear which directions our sector must reorient around, and rapidly: a sharply increased emphasis on a retrofit/reuse/redistribute approach to our existing built fabric, and with careful new build 'in the gaps', tuned to specific needs. The implication for architecture and construction is significant: a large scale reorientation towards repair which suggests, in the words of architectural collective MOULD (2025), *"a steady-state model for architecture (which) redistributes, renews, repairs and maintains existing resources"*. Such 'steady-state' thinking draws from the earlier work of Hermann Daly, Donella Meadows, EF Schumacher and others, as well as today's *Doughnut Economics* and *Planetary Boundaries* frameworks—all inspirations for Circle's approach, both in conception and visualisation.

In this vision, both retrofit and new build must be produced almost exclusively from bio-based circular materials from regenerative local sources wherever possible. This transformed practice of building includes retrofit and deep renovation, which can cut emissions by 50–75 per cent when compared with new construction (UNEP 2023). As such approaches work within existing spatial boundaries, they also mitigate against urban sprawl's damaging land-use and ecosystem loss. If carried out equitably, via participative strategic design, retrofit can ensure that existing communities, and their associated social and cultural values, are maintained and reinforced.

The emphasis of this work is on materials, and how they might be sourced, assembled as buildings and spaces, such that they can remain continually valuable afterwards. Framing the agenda around *absolute sustainability* (Mossin et al 2023; Horup et al 2025) means that our sector must reorient around actually 'good' buildings rather than simply 'less bad'. There are many ways that this can be interpreted—*sustainable, regenerative, non-extractive, non-polluting, safe, healthy, equitable*—yet all must work within the planetary boundaries of *absolute sustainability.* This will require far greater creative energy and insight than we have seen in the last few decades of architectural practice.

Local Resource/Collective Knowledge GXN/3XN, Royal Danish Academy (2025)
Exhibition installation at Venice Architecture Biennale 2025 exploring a place-based architecture. Each panel of the three-part tower embodies work with different places, and therefore different local bio-materials, communities, and crafts, from 3D printed blue-biomass in Veneto, to palm weaving in Cuba, to bacteria-grown concrete in Denmark. Technical assistance from Ramboll, Biomason, Università Iuav di Venezia, and others listed here.

Equally, as noted earlier, and in the Australian Reduction Roadmap (Crawford et al 2025) and its Danish forerunner (Reduction Roadmap 2024), a recalibration of the sector, more responsibly aligning supply with actual needs, will be required in order to achieve the necessary reduction the overall volume of building, and thus materials. The rationale for this reduction is noted in the introduction to this report: when assessed from a systems perspective, the construction industry, and broader built environment sector, is perhaps the most significant driver of climate crisis, resource depletion, biodiversity degradation, and waste generation.

Business-as-usual barriers

Circular materials for a regenerative construction system present as 'radical' innovations to those current construction practices. Much sectorial research or industry-led advocacy focuses on productivity in the construction sector, largely irrespective of *the direction* of that innovation (Premakumara and Siriwardana 2025), including in Australia (CEDA 2025). Such research and advocacy appears to be almost entirely unaware of the the sectors's more systemic social, economic and environmental challenges. As noted, increases in efficiency and productivity, pursued as if they are outcomes rather than means, and without changing the strategic direction of the sector's activities, will simply produce greater extraction more rapidly (Hickel and Kallis 2020).

Locating innovation around **absolute sustainability** instead means creating a built environment sector, and set of associated everyday practices, that works well within planetary boundaries. That will mean processes, systems and technologies both fast and slow, efficient and inefficient-but-effective, reliant on both automation and algorithm as well as the different cultures of embodied, careful human-led place-based craft practices, old and new.

Despite this need for broader perspectives. using the discourse around barriers to adoption of industrial innovation is still useful in the context of this project. Such barriers are well understood (Rogers 2003) and can be conveyed via five principles: **relative advantage, complexity, compatibility, trialability,** and **observability**. Each of these maps onto the approach outlined in Circle.

The value, or **relative advantage**, of a new material or system is the degree to which an innovation is perceived as being better than the idea it supersedes, particularly from the perspective of the end user. With building industry, the notion of 'end user' is complicated, and typically relates to the developer, builder or designer, rather than the actual 'end user' of the building. With the former definition, the *industry* end user, value is often expressed in financial profitability (through increased revenue and/or decreased cost) or in status giving (such as brand value, mapping onto financial return over time).

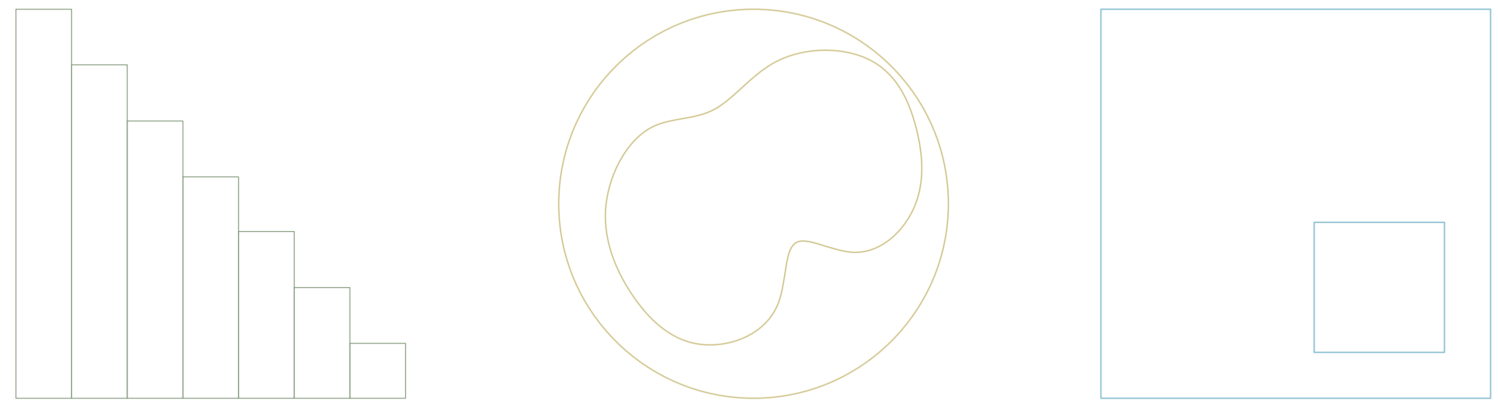
The nature of the innovation largely determines what specific type of advantage (such as economic, cultural, or social) is important to adopters. With *circular* materials, relative advantage is perceived as environmental value initially, with related social, cultural, and local economic value following. Such value assessments will vary according to the perspective of the user and both objective and subjective views of the importance of circularity, emissions, and ecosystem impact, as per the Circle framework. When the user weighs these 'planet-aligned' factors higher, the relative advantage of circular bio-based materials is increased and more likely to be adopted.

In the context of transitions, a user's valuation of circularity is critical to its early adoption. The increased cost of circular materials compared to conventional materials, which is generally the case in a transition due to the path dependency of legacy infrastructures and practices, is an obvious disadvantage to the adoption of circular materials, and captured within the 'industry-aligned' factors of production scale, time, and durability. Where circular materials can demonstrate a second complementary (traditional) advantage, such as being cheaper than conventional materials, they are typically more likely to be adopted.

As we will see, policy and regulatory change can correct for the relative perceived advantage of legacy

Circle / **Conclusion** / Overview

An emerging mission-oriented innovation portfolio for housing within planetary boundaries



Australian Reduction Roadmap v1 (2024)

Circle framework v1 (2025)

Housing Plan B (2026)

extractive materials, incentivising instead circular materials from regenerative sources. Whilst the sunk capital, and sometimes 'stranded assets', of industrial infrastructure is slower to react, using public policy—like planning systems and innovation policy—alongside regulation—like building codes and standards—can quite quickly shift the systems in question. Equally, our discussions with industry partners indicated that many circular bio-based materials—such as the straw cassette systems in the *Hyllie* housing tower in Malmö—are already within price range of standard industry-aligned materials, and with no particular additional maintenance costs anticipated. Although subsidies are typically required to trigger systemic change rapidly (perhaps with financing drawn down by mitigating against future climate risk or health outcomes), such policy changes are powerfully 'tilting the playing field' in favour of common good outcomes (Mazzucato and Hill 2024). Circle's proposed framework suggests a value model which might allow such co-benefits to be estimated, understood, and captured.

Complexity is the degree to which an innovation is perceived as relatively difficult to understand and use. Any new idea, material or system may be classified on a form of continuum from complexity to simplicity. Some innovations are clear in their meaning to potential adopters while others are not. Although research evidence is far from conclusive, it is suggested that the complexity of an innovation, as perceived by members of a social system, is negatively related to its rate of adoption.

Yet clear benefits emerge from the often simpler systems involved in circularity, typically in *'subtraction'* or *'avoidance'* strategies. An example may be the compressed straw panels described earlier, which are both structural and insulating at the same time, obviating the need for separate systems for either. Further, this increased insulation integrated into structure might largely eliminate the need for complex heating, ventilation and air-conditioning (HVAC) systems. This approach to building envelope might be contrasted with what Bordass et al (2025) call *"a people-first approach to retrofit"*, in their paper *'How to Sail a Building'*, on actively adapting a building, including its fixtures, furnishings, and inhabitants' clothing and patterns of habitation. In either of these approaches, the tangled of services in contemporary buildings might be hugely significantly reduced in mass. Along with shifts to wireless digital connectivity, this frees up valuable volume currently taken by drop ceilings.

Similarly, a contemporary laminated veneer lumber (LVL)-based apartment building like *'Xylino'* in Almere obviates the need for a concrete core, via a precise interlocking modular timber structure (also designed for disassembly). The 103-unit, five-storey assembly has a simpler, lighter construction process, composed of 436 prefabricated modules produced off-site before being lifted into place via smaller cranes than typically used. The project was completed within four weeks. Metsä Wood says its LVL product for *Xylino* is 50 per cent more resource efficient than mass timber (Metsä 2026).

Such methods of simplification via circular material use can mean a reduction in the quantity of physical matter required in a building, as well as its complexity and cost. It should also lead to increased reliability, resilience, reduced maintenance and running costs, and reusability.

> Avoidance is about simplifying construction. At a materials level, it might entail choosing a material with one or more performative properties, for instance, choosing a rain screen material that also acts as a wind barrier. Or choosing a façade or roofing material that makes additional construction layers like vapor barriers unnecessary.
> Natalie Mossin and Ingeborg Hau (Mossin et al 2023)

Circular materials are not hard to design with, use, or maintain. It is their *relative* novelty that creates complexity in a well-established industry of standard construction systems. This is especially the case where a single circular material replaces a conventional material as part of a construction assembly, and is less of an issue where the whole assembly is replaced (e.g. a circular façade system may be less complex than replacing aluminium for timber in a traditional facade assembly).

Regulations tend to promote the use of standard construction systems via *'deemed-to-satisfy'* provisions in the National Construction Code. Many circular innovations do not fit within this standardised, legacy construction model by definition, and require alternate compliance, and thus additional cost, which transfers the risk of systems performance on to the certifying consultants, builders and subcontractors. For example, rammed earth walls were removed from the National Construction Code two decades ago, and are no longer able to comply within the easier *'deemed-to-satisfy'* pathway. Being effectively unregulated within the building code means added effort, delays, and costs, translating directly to reduced adoption for a material well-known to be an ideal building material for hot climates. There may be little justification for this approach, particularly when viewed holistically through a proposed framework like Circle's, yet untangling and simplifying the code is not part of the Commonwealth Government's agenda in the near term (Hill 2025).

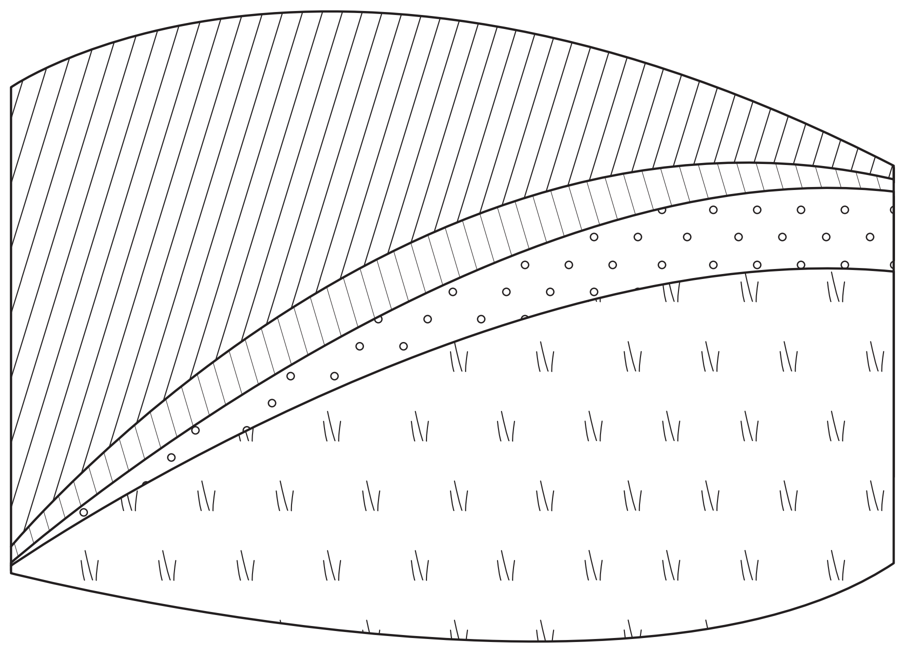
Compatibility is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters. An idea that is more compatible is less uncertain to the potential adopter. An innovation can be compatible or incompatible with sociocultural values and beliefs, with previously introduced ideas, or with client needs for innovations.

The novelty of circular materials results in fewer skilled workers and greater reliance on experienced contractors who can work with the new materials. Innovative materials may also require new manufacturing equipment and specialised tools for onsite assembly. In Australia, mass timber construction is a relatively recent example of a previously novel material that has received extensive experimentation and significant investment into manufacturing and onsite specialised tools. Whilst the adoption of mass timber in Australia has not had the benefit of coherent public direction-setting, as will be discussed, it is increasingly established as a 'niche', in transition theory terms (Kemp et al 2007). Early adopters of such timber technologies have demonstrated to others how these new systems create an additional relative advantage beyond the circularity factors (for example, the reduced onsite labour requirements of mass timber construction, decreased waste, increased speed, and so on).

Enabling compatibility and overcoming complexity can be driven by **trialability**. This is the

Home Truth, Melbourne Breathe (2025)
Exhibition installation at National Gallery of Victoria, designed by Breathe. A frame silhouette outlining the typical footprint of the Australian home, at 232m2 (Australian Bureau of Statistics, 2023) now the world's largest. Within the frame an interior volume, marked in rooms constructed from tightly-arranged timber slabs and silver-flecked Saveboard, made from 100% post-consumer waste. This suggests a 100m2 volume, typical of those built in the early 20th century. The installation is designed for disassembly and reuse.

Sankey diagram indicating required shift in focus and energy of architectural design



degree to which an innovation may be coherently experimented with. Put simply, an innovation that is trialable is less uncertain for the potential adopter, leading to increased adoption rates. System actors, such as public sector agencies, research funding bodies, and universities, can all create conditions for trialability, as a core function of a national innovation system.

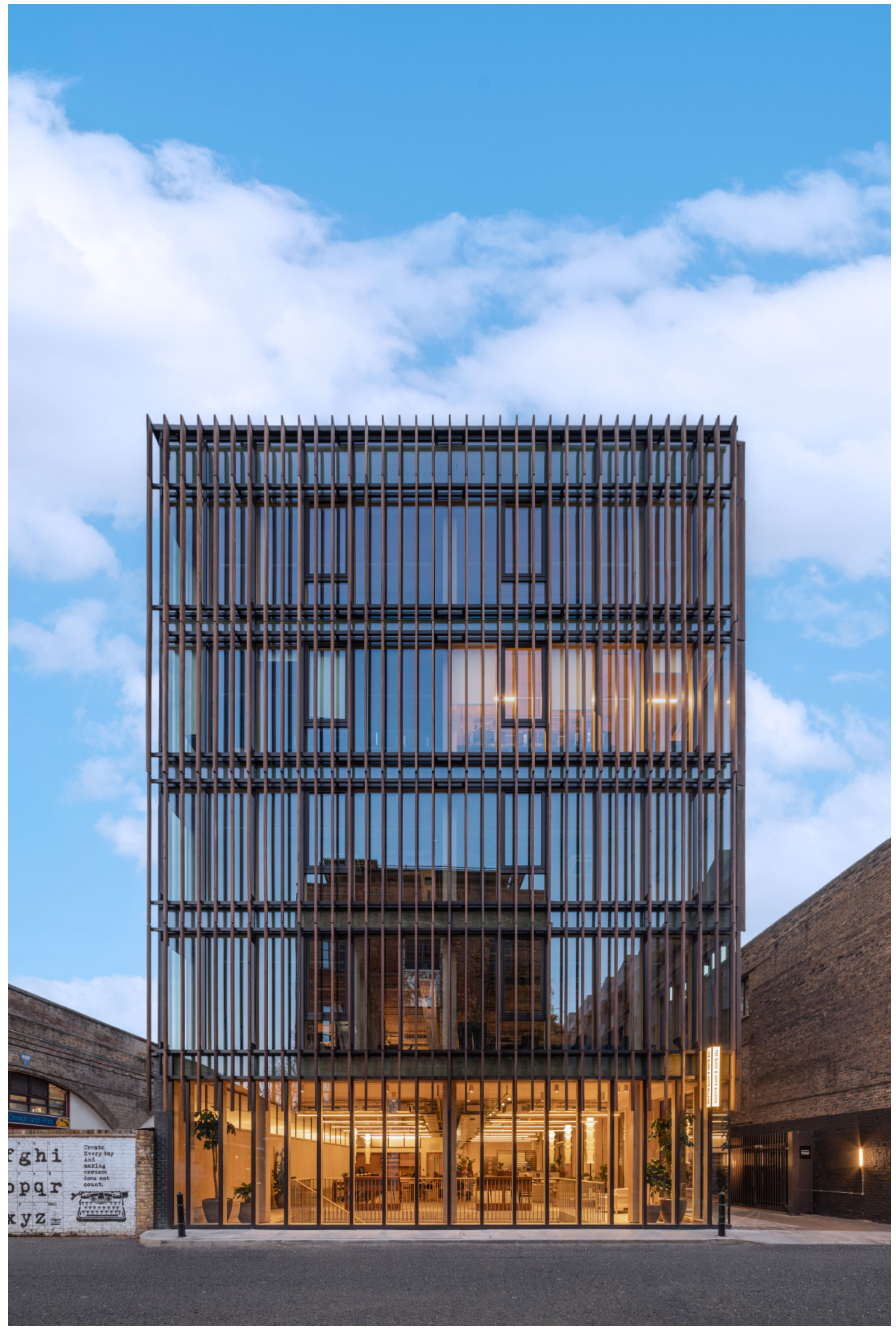
An example would be the emerging interest in tensioned stone, exploring its ability to utilise the compressive strength of stone combined with the tensile strength of steel to create structural elements as a replacement for concrete. How to refine, test, certify, communicate, and train for such new building methods? How should code change?

Trialability works along a spectrum from 'the lab to the street'. The Future Observatory's *Stone Demonstrator* pictured earlier (p.120–121) indicates the latter; a public systems demonstrator in 'the street'. To get a technology to this point requires work in lab, workshop, and studio. Incentives to create and test systems demonstrators will significantly aid the adoption of innovation in the design and construction industry, including the creation of building a flexible innovation and research environment for prototyping, testing, and the updating of building code. (In discussion, some industry partners suggested that Australia's national product testing and certifying capability should be better resourced.)

This form of trialability leads to **observability**: the degree to which the results of an innovation are visible to others, and which is also positively related to its rate of adoption. The diffusion of mass timber construction through the industry has been led not merely by its possibility, or its potential technical, environmental, or financial advantages, but through built examples. These also sit on a continuum, from exhibitions, competitions, and installations —like 3XN/GXN's *Local Resource/Collective Knowledge* exhibit at the Venice Biennale pictured (p.147) or Breathe's *Home Truth* (p.151)—through to actual buildings. Private, public, and community sectors each have a role to play in developing and communicating observable building innovation, and often in collaboration.

Whilst a single prototype or demonstrator cannot transform a system, each prompts development in technical invention whilst also revealing aspects of the 'dark matter' of policy, code, financing, supply chain, and organisation that can enable scaling and spreading. Crucially, however, as buildings transform abstract ideas, like circularity,

Black & White Building, London Waugh Thistleton Architects (2022)
The largest fully engineered timber office building in the City of London has beech laminated veneer lumber frame with cross-laminated timber slabs and core allowing a highly flexible interior. Of particular interest is the bespoke 'end of life and beyond life' strategy for the structure, which is 60 per cent reusable, 35 per cent recyclable, with only 1 per cent destined for landfill, based on innovation in design such that the structure can be demounted and reused (WTA 2024).



into settings to encounter those ideas, it is the material reality of buildings that help shifts perceptions, assumptions, and ultimately paradigms.

In summary, the perceived novelty of circular bio-based materials in a risk-averse industry that has traditionally limited its investment in R&D likely contributes to lower adoption. Increasing industry-wide acceptance will necessitate easier compliance, flexibility and invention in regulations, simplified construction methods, and incentives to produce prototypes and demonstrations that highlight their advantages over conventional materials.

Ultimately, overcoming industrial barriers to circular bio-based materials from local regenerative sources will likely require a combination of public systems demonstrators that can create a societal and industrial *'pull'* in terms of demand, alloyed to a public leadership *'push'* in terms of policy, regulation, education and training, infrastructure development, financing, and procurement.

Technology (alone) will not save us

This emphasis on public leadership reflects the inability of the private sector to transform itself, at least in this context.

Research on the English, Danish, and German built environment sectors suggests that technological innovation in design and construction will not be able to achieve their environmental policy and regulatory commitments (zu Ermgassen et al 2022; Napiontek et al 2025; Horup et al 2025).

> By modelling future construction in Denmark (2025–2050), the study finds a significant divergence from current consumption patterns and exceedance of the planetary boundaries suggesting that technological advancements cannot alone take construction in Denmark towards sustainable practices. The study therefore suggests a shift towards biobased materials and reduced construction activity as viable mitigation strategies.
> Horup et al (2025)

It would be highly risky to assume that Australia's sectors may be more technologically advanced in these respects.

This perspective also indicates why Circle concentrates on the systemic flows of materials through the cultures of buildings, rather than narrower processes of modular fabrication technologies within that. Whilst research in the latter is fundamentally important in order to lift Australia's production capacity to international standards (as noted in the sections on material assemblages), without more fundamentally transforming our relationships with the materials and spaces we are fabricating with and for, such efficiency gains frequently lead to increased resource use, not less (Hickel 2021; Saito 2024; Fressoz 2025; Stangl et al 2026). In other words, focusing on fabrication technologies, without shifting perspectives on our material supply chains first, leaves our overall resource use increasing and extractive; merely a 'less bad rather than good' alternative.

Even in those high-income countries in which greenhouse gas emissions may have been decoupled from economic growth, Vogel and Hickel (2023) find that *"these countries would on average take more than 220 years to reduce their emissions by 95%, emitting 27 times their remaining 1.5°C fair-shares in the process. To meet their 1.5°C fair-shares alongside continued economic growth, decoupling rates would on average need to increase by a factor of ten by 2025"*. Needless to say, this did not happen by 2025. Equally, focusing on emissions does not account for the other extractive environmental impacts of the built environment sector, to some extent captured in the Circle framework under 'ecosystem impact'.

Yet all of this appears to be little understood, with a supply-side, productivity-oriented, and growth-based agenda dominating political, industrial, and public imagination in countries like Australia. A significant recalibration is required, particularly around the materials and environmental systems that are the subject of this study, as well as recognising the value of the buildings and spaces we have already constructed—particularly in Australia, where we have *over-produced* housing and commercial space, compared to population increases

and household size, never mind future demographic projections (Hill 2025). In fact, a growing set of disparate initiatives suggests that little short of a complete halt to new construction may be required, allowing for a reset to orient around climate and biodiversity action and social justice—from the *Byggestop* (Jørgensen and Lee 2024) or *HouseEurope!* movements, to the various *Demolition Atlases* in Germany, Sweden, Switzerland, and UK, or indeed Malterre-Barthes' proposed moratorium (2025).

Within this Australian context, however, a pragmatic, engaged approach would be to recognise that research like the Reduction Roadmap describes the envelope we have to work within, whereas frameworks like Circle presents an analytical, practical and generative material palette that could work within these planetary boundaries. As noted, beyond Roadmap and Circle, a holistic strategy must bring together questions of building supply, and therefore material supply, and actual needs.

In both cases, the Circle framework indicates the material palette should consist almost entirely of bio-based materials from local regenerative sources, alongside the inventive and resourceful re-use of existing materials. The Reduction Roadmap document describes the range of strategies we need to bring together, ranging from renewable energy for production to fabrication infrastructure, from policies to incentivise mass retrofit and equitable downsizing to fiscal innovation, from architectural invention to innovative public procurement.

The next stage for Circle, following a mission-oriented innovation framework, would be to transform its analysis into strategic prototypes. Strategic prototypes, after Hill (2022), can reveal the alterations required in building codes, planning policy, standards, lifecycle guidelines, organisational models, supply chains, consistent material passports, etcetera, all of which combine to enable innovations to spread and scale across systems and cultures. Yet as they are built outcomes, they also help stimulate and enrich public and industry imagination, by making possibility tangible, creating settings to encounter new forms of constructed materiality. Whilst we have great respect for the various calls for moratoria on new building, we believe that to reimagine building we have to build—albeit in new ways that drive towards the same shared outcomes.

Getting Australia to Denmark

Whilst *'getting to Denmark'* was once shorthand for progressive policymakers (Fukuyama 2014), Denmark continues to provide a reference point within this particular work for a number of reasons. The collective, multi-sectorial advocacy behind the Danish Reduction Roadmap led to the first meaningful 'ceiling' on lifecycle emissions in construction—including embodied emissions—making Denmark perhaps the first industrialised nation to truly begin working through this transition. Our discussions with Denmark-based colleagues reveal that the impact of the regulation as it works through industry and government practices, revealing many new challenges.

Equally, we must also note research that indicates that Denmark's overall economy is calculated to be only '4 per cent circular', which is considerably lower than the estimated global average of 7.2 per cent (Circle Economy, 2023). Much of Denmark's building industry, public authorities, and education institutions might also be said to be still in 'business-as-usual' mode, depending on one's perspective. The public and industry discourse concerning climate action in regulation and public policy is far from resolved.

Nonetheless, Denmark's built environment sector, including its public leadership, is taking meaningful steps forward. Its Reduction Roadmap (2024) inspired the Australian Reduction Roadmap in turn (Crawford et al 2025), not least due to colleagues at Danish-Australian architecture practice Terroir working across both countries.

Denmark's built environment innovation ecosystem includes an engaged public sector with significant state and municipal capacity and capabilities, design practices large and small with material innovation to the fore, a strong civic and philanthropic sector including Realdania, a slew of inventive developers, and an integrated academy, not least at DTU and Royal Danish Academy. Some of the projects noted here—whether Pihlmann Architects' deep renovation or locally-farmed school buildings by Henning Larsen—or the many others elsewhere, such as the installations by Reværk, Leth & Gori, and Lokal in the *4>1 Planet* initiative's *Next Generation Architecture* competition (Petersen 2025), indicate the breadth and depth of this system already at work.

More broadly, the Nordic context indicates how to balance public, private and civic sectors working together around challenges and missions (Hill 2022). A coherent and engaged approach to the public sector is not at the *expense of* a thriving, inventive private sector; quite the opposite. For example, the Australia Institute's Richard Denniss notes that the Swedish private sector has had double the productivity growth of Australia's for the last 25 years, and with stronger wage growth, a high quality of life and a broad and deep welfare model based on higher taxation rates and greater state capacity (Denniss 2025).

More importantly, in this model those productivity improvements can be directed by societally-set shared outcomes rather than continued extraction. Transforming the built environment will require concomitant transformation in public leadership, based around cultivating 'dynamic capabilities' and state capacity across city, regional, and national government (Kattel et al 2025). This, in turn, creates the conditions for privately-led innovation actors to be able to thrive, working to shared directions.

The role of public code

Notwithstanding the innovation potential of the private and community sector, these Danish examples indicates that a publicly-led innovation agenda, capable of deploying the full array of public tools, is essential to systems change. Of course, this perspective is not unique to the Nordic region.

Assessing the UK in this context, Martin et al (2024) find that a systemic shift to the circular economy is *"impeded by barriers such as inadequate policies, design complexities, limited knowledge, bureaucratic delays, and exorbitant costs (such that) promoting eco-industrial networks and innovative waste management practices necessitates synchronised policy instruments, such as recycled content targets and eco-design standards"*.

As in other countries, the Australian National Construction Code (NCC) has traditionally prioritised safety and structural integrity. In 2006, energy efficiency of passive building performance and active energy systems was added as a third pillar. Yet material choices are only considered in this context: whether they contribute to one of these three pillars (e.g., concrete for structural integrity, fire retardant materials for life safety, and fossil fuel-based materials like polystyrene that are deemed desirable for their high insulation properties). None of the above promotes the use of circular materials.

A reimagined construction code, reoriented around sustainability, would correct the current inherent bias towards conventional extractive material use. This would help shift the components of the 'industry-aligned' material choices outlined earlier, such that they become 'planet-aligned'. In the short term, this would include setting an appropriate ceiling on embodied emissions in construction, as per Denmark, moving towards a recognition of the planetary boundaries framework in the Paris Agreement. Without this, the legislation around construction remains open to citizen-led legal challenges as per the Netherlands, Australian industry falls further behind global best practice, and new and existing buildings continue to reproduce and exacerbate climate risk, biodiversity degradation, and resource depletion.

Such a 'ceiling' presents a target for industry to innovate within. Alongside this, a complementary pathway could encourage the use of non-mainstream and novel materials, leading the transition from the building materials and products themselves. These incentives might include financial subsidies (with their cost covered by the many 'upstream' savings that such materials will produce) or pre-approved fast-tracks via integrated standards and digital material passports. (Surrounding the construction code lie further layers of 'dark matter', including product standards, numerous forms of software and database, financing and investment, and fiscal policy. Public Realm Lab have used their various projects involving hemp masonry to organise and advocate for material standards to be upgraded in Australia.)

Master Builders Victoria headquarters, Melbourne Fieldwork (2025)
The 'deep renovation' of the Master Builders Victoria headquarters in Melbourne has been designed by Fieldwork. Stripping away the previous eras of renovation from within the 1967 original building revealed material and spatial qualities that could be uncovered or re-used, whilst introducing new bio-based elements such as timber window frames.

Risk aversion presents as ambiguity and uncertainty as to the performance and cost of circular materials, at least when compared to legacy materials protected by the construction code's pillars. Ways around such manufactured risk aversion would include reorganising how risk is carried across a more *integrated* built environment sector, via innovation missions that pull together product manufacturers, certifiers, designers, builders, building owners around regenerative approaches to construction, led through prototypes, systems demonstrators, competitions and prioritised research funding. Other industries, such as automobile or consumer electronics sectors, have all begun to reorganise and manage risk across more circular product lifecycles, leading to clarity over shared responsibility, from sourcing to manufacturing, operations and maintenance, and end-of-life or recycling.

There are no technical reasons why the built environment remains so anachronistic in these respects, particularly in Australia. As noted earlier, the 'dark matter' of regulation like building codes can be a creative material to design with, rapidly driving such change through a system equitably and responsibly. The changes in Danish planning and construction regulation, in terms of reorienting products, practices, and places, indicate the speed by which this can happen. This is in part due to existing investments in prefabrication capability, as with other Nordic, central European and many East Asian countries, in which their manufacturing systems can be reoriented around different material supply chains. Equally, such policies necessitate new permitting, approval, maintenance, renovation and retrofitting capabilities. Needless to say, this can be conveyed as a meaningful increase in new crafts, technologies and jobs, in turn requiring education, training, and research capability-building activities. This would be a highly meaningful and valuable agenda for a *Future Made in Australia* industrial strategy.

The National Construction Code sets the frame that the built environment sector works within, alongside planning regulations and public procurement activities. Without a meaningful transformation of the code, reoriented around a regenerative approach to construction, little change is likely to occur. The corollary of this is that a redesigned public code provides the most powerful, non-negotiable, and legitimate tool for transformation at scale. The Circle prototypes, if pursued to built outcomes, can be seen as physical embodiments of 'the code we need', each a form of 'dark matter probe' (Boyer and Hill 2013) discovering and revealing the current flaws in a system and culture organised around extractive practices, as well as the possibilities inherent in a reframed code.

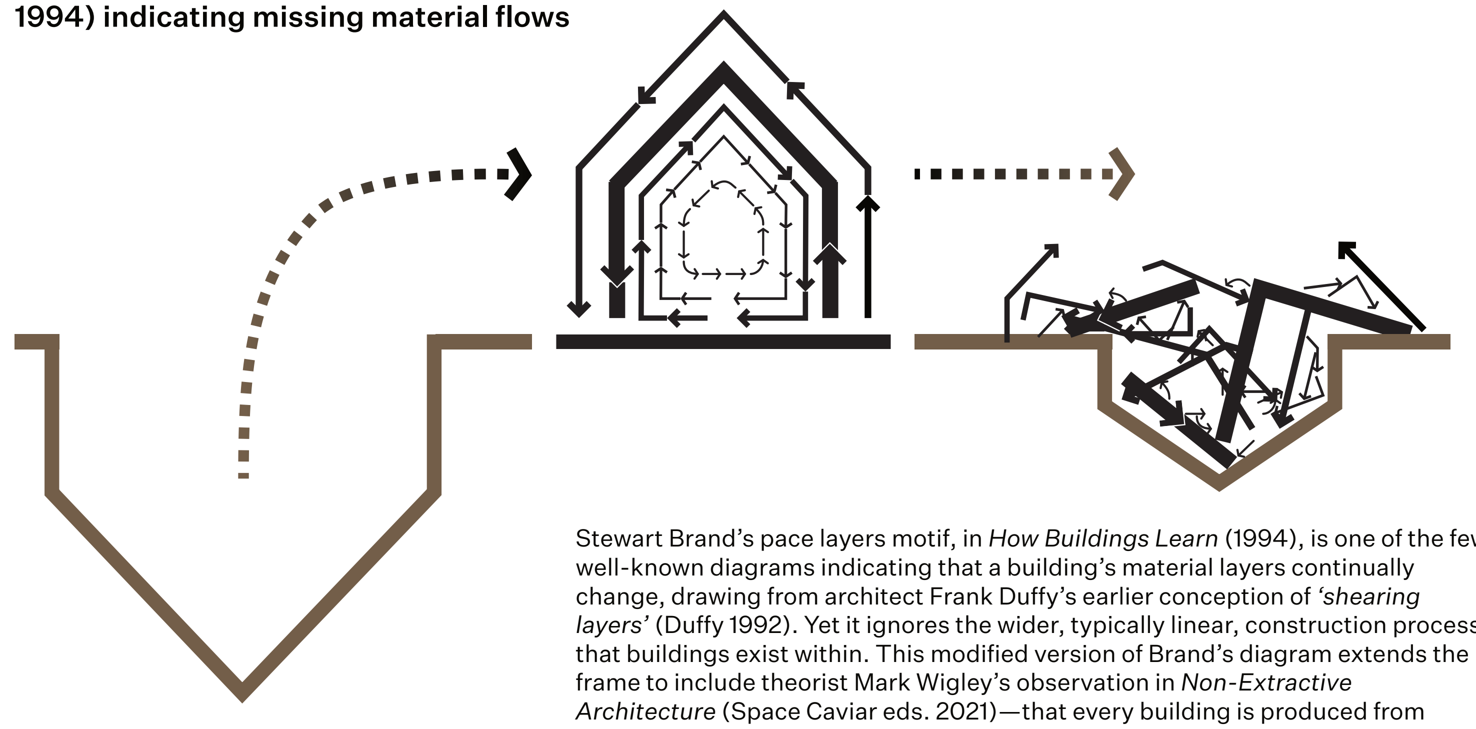
The role of public procurement

In parallel, public procurement can create and direct markets. France gives us a powerful example, linking particular bio-based material outcomes to planning regulation, and by using its significant public procurement of new constructions to drive this through. The French Government announced in 2020 that all new public buildings are to be built from at least 50 per cent timber or other natural materials (French Government 2020). As noted in Leloup et al (2022), this has transformed the sector for timber in particular, not only through procurement of public housing, but of schools, sports centres, and other municipal buildings.

> Since 2020, wood has been moving up a notch on the construction front. This is a rebound effect triggered by the 2015 Paris Agreements. The combined power of the state and Europe is generating action in favour of the ecological transition, and the relevant planning bodies are adapting these national policies to the various territories, and mainly to the cities.
> Patrick Molinié (Leloup et al 2022)

Yet other bio-based material approaches are being developed as a result of this publicly-guided direction-setting. As pictured (p.77), *Quatre Cheminée* (2024), designed by Déchelette Architecture is a four-storey building with eight social housing units, caretaker's lodge, and a shop, constructed using a timber structure and self-supporting prefabricated raw earth blocks, placed on a stone base. The rammed earth is locally sourced, specifically from the excavation of the nearby Greater Paris metro.

Modified pace layers diagram (after Brand 1994) indicating missing material flows



Stewart Brand's pace layers motif, in *How Buildings Learn* (1994), is one of the few well-known diagrams indicating that a building's material layers continually change, drawing from architect Frank Duffy's earlier conception of *'shearing layers'* (Duffy 1992). Yet it ignores the wider, typically linear, construction process that buildings exist within. This modified version of Brand's diagram extends the frame to include theorist Mark Wigley's observation in *Non-Extractive Architecture* (Space Caviar eds. 2021)—that every building is produced from *"holes of extraction"* elsewhere— and that just as materials existed before the building, they will continue to exist after. A building is a particular assemblage of those materials at that point in time. The drawing indicates that the current destination for building materials is generally landfill, suggesting, by omission, the potential in reorienting around circular material flows instead.

Elsewhere, the 1966 public housing block *Les Olympiades* in Pont de Claix is being renovated with straw insulation. This requires the addition of simple protective eaves for protection from rainwater, as well as lime coating (Oikos 2025).

At Rue des Couronnes in Paris, the social housing landlord Paris Habitat has experimented with earth construction in landscaping and car park removal, working with local Masters of Architecture students from ENSAPLV (Rougelot 2025).

At Nogent-le-Rotrou, a small town in the Loire Valley Central region, 13 social housing units have been constructed in prefabricated straw and wood elements, designed by NZI Architects for social housing agency Nogent Perche Habitat (Grillo 2020).

Each of these examples from France indicate the power of using public procurement of social housing as a lever to transform the construction sector.

> We must develop the construction of housing, schools and office buildings in wood to reduce the carbon footprint of buildings, reduce construction costs and enhance the value of the French forest resource. This is what our fellow citizens expect of us.
> Julien Denormandie, French Minister for Agriculture and Food (in Leloup et al 2022)

We might see the same in earlier strategic design-led innovation practices, helping to shift Finland's building code to allow for mass timber (Hill 2012) or in recent procurement of schools in Denmark, allowing Henning Larsen to develop its building techniques in straw (pp.48–49; p.129). As noted in the introduction, the shifts in planning codes in London towards 'retrofit first' approaches (Hirst 2025) have helped firms like 3XN/GXN develop new methods for old buildings and existing materials. Similarly, the Regional Urban Planning Regulations of the Brussels-Capital Region can reinforce a meaningful starting point for design and construction: *'Every existing building will be conserved and, if necessary, renovated'* (RUPR 2024; Van Gerreway, C. 2025b)

Retrofit requires significantly more creativity and care than the dangerously influential myth of the *tabula rasa* typically valorised in the last decades of architectural culture (MOULD 2025). Regulation helps shift the goalposts towards 'common good' outcomes, stimulating designers and builders to respond in return. Based on our industry discussions, we have little doubt as to the capabilities with which much of the industry would respond in turn. (The authors work in a graduate school of design, and we hear similar from our students). A very different architectural culture is emerging from the niches, starting with the materials and buildings already in place. However, regulation and policy sets the conditions for their work, and must transform to become a tailwind supporting this direction of travel, rather than a headwind.

> There are always initial conditions. Our task is to find value in the materials that are there at the beginning. I want me, the place, the materials, the methodology to stay within the same space and inspire one another for a longer duration. Place translates itself with the architect as a part of that translation. Peel off the layers to see what's behind the facade, to understand the circulating logic of things and their material, biological, and historical properties.
> Søren Pilhmann (Dickinson & Pihlmann 2025)

Resetting the 'system settings' (Hill 2025) to more fundamentally engage with materials and these existing *"initial conditions"* is not merely pointing the existing market—legacy industrial sectors, fiscal policy, consumer perceptions and all—at the complexity of the built environment sector and hoping for the best, but directly creating and shaping a market (Mazzucato 2021).

Little of this culture currently exists in Australia, where an 'administrative tradition' (Peters 2021) tends to mitigate against such market shaping, at least in this direction, and there is extremely limited public procurement and operation of housing by international standards. The 'dynamic capabilities' (Kattel et al 2025) and state capacity required to drive such public leadership has, in Australia and countries like it, been eroded through outsourcing, as described by Mazzucato and Collington (2023).

Yet Public Realm Lab's Mildura project (p.40–41), as the first hemp masonry public building in Australia, indicates that it is not impossible, just as our reference to the Commonwealth Experimental Building Station indicates that Australia has led through such public innovation in the past.

It is worth remembering that the now-dominant materials in the 'industry-aligned' set were also niche materials at one point. It's as if it is easier to imagine the end of the world than the end of concrete as a construction material. Yet reinforced concrete was also construction innovation a century ago. Although forms of concrete have been in use since at least early Rome, the transition to reinforced concrete at scale occurs during the early 20th century, as concrete was actively moved through several decades of 'novel material': untested at scale, unaffordable, and with little social acceptance (Mack 2019). This shift from non-mainstream innovation product to 'business-as-usual' was often enabled by publicly-led innovation, such as the first waves of large-scale public housing and built infrastructure during this period.

Our discussions with practices indicate a firm desire on behalf of many design, product and property development organisations to actively seek out 'planet-aligned' materials, and prioritise them within projects. They are finding inventive ways to circumvent barriers, working to close the gaps between financing, standards, and production and building systems. Yet with the grain of the existing Australian built environment sector largely working against them, individual design practices are left dependent on the motivation of clients—or instilling motivation in clients, or becoming clients. It is unfortunately common for the best intentions of both the designer and client to be beaten by barriers built into the systems of building production—headwind rather than tailwind. For both large and small scale projects, the costs of perceived risk can prevent designers from considering alternate materials. In particular projects, motivated designers and project teams can seek out co-benefits—such as health and wellbeing benefits, brand value to the client, new business models, or innovation and research financing. Yet these individual projects cannot shift a system.

Wilya Janta Explain House 1, Tennant Creek Wilya Janta and OFFICE (2025)
OFFICE worked with Wilya Janta, an Aboriginal-led organisation dedicated to bringing culturally safe and climate-appropriate housing to remote Northern Territory, and in collaboration with a Warumungu family, to design a house that could work with local environmental conditions and repeatable construction techniques. A defunct 'brick machine', previously used to construct a petrol station and the local arts centre, was pressed back into service to make mudbrick tiles for the home's breezeway and living areas. The tiles are made from locally-sourced termite mounds and spinifex grass, providing thermal mass and comfort within the lightweight structure.

Public projects, led by city or state government policy and other public and civic actors, can use their market-shaping capabilities to set directions, whilst meaningful and well-crafted legislation holds projects, and actors, to account. Within this more supportive innovation environment, public, private, and community sectors actors can collaborate to produce an equitable regenerative construction sector, balancing both care and urgency.

The role of public prototypes

How to take a small step in this direction, indicating the way? As stated, we believe that to reimagine building we have to build. This possibility has to be made tangible, allowing people to encounter the idea of a regenerative architecture and construction sector. Buildings reveal the existing patterns and dynamics within our broader systems and cultures, consciously or otherwise, and so *prototype* buildings allow us to better understand our *possible* systems and cultures.

> People don't have a problem imagining what a four-lane highway would look like. But to imagine a restored landscape of over a million hectares—nobody knows what that would look like because it hasn't really been done before.
> Tim Christophersen, Nature for Climate, UN Environment Programme (Rose 2021)

As well as emerging arrays of exciting novel materials, the materials used to articulate the Circle framework's 'planet-aligned' set are selected as they exist in Australia, and abundantly so. Many have been used in buildings for millennia. Whilst there is more data to produce and refine concerning lifecycle emissions and ecosystem impact, sufficient research has already been conducted to reinforce their significant advantages over the industry-aligned set, at least when evaluated in the context of our climate and biodiversity crisis. In that sense, the background research is 'done', just as our legally-binding international agreements like 2015 Paris Agreement indicate that the direction is also clear.

Hence, the emphasis must be on action in the foreground, on demonstration, for as Donella Meadows pointed out, the most challenging leverage points in systemic change concern *"paradigms … the shared social agreements"* from which systems emerge (Meadows 2008).

> All it takes is a click in the mind, a falling of scales from the eyes, a new way of seeing
> Donella Meadows (2008)

Strategic prototypes allow us to shift perspectives through experience, a 'new way of seeing' that might prompt these 'clicks in the mind'.

Clearly, the material innovation highlighted by the Circle framework would be articulated by all three prototypes—**Green**, **Blue**, and **Aqua Houses**—as noted earlier. There are numerous technical and craft-based questions here, regarding growing, sourcing, refining and manufacturing of new bio-based materials or existing materials, the details of design-for-disassembly, the simplification strategies outlined earlier, or the different practices of care required. Such prototypes would be most influential when located in public spaces, and associated with inventive engagement programmes.

Yet through the processes and practices of making, they can also reveal the missing mass of 'dark matter'—building codes, planning regulations, standards and guidelines, value models, governance frameworks—that enable an equitable scaling and spreading from prototype to systems demonstrator to policy and regulatory change (Hill and Melander 2025).

This 'missing mass' would include the footprint of buildings, as per the modified version of Stewart Brand's 'pace layers' diagram (p.159), suggestive of the materials flows, and potentially loops, at play in construction. This would reverse geographer Val Plumwood's notion of '*shadow places*' (2021)—the (typically) 'Global South' places that are extracted from in order to build the 'Global North', yet which remain *'out of sight and out of mind'*. Built prototypes can be complemented by associated visualisations—via augmented reality interfaces, digital material passports, or simply well-produced physical documentation and signage—deliberately shining a light onto the shadows of current supply chains and their origins, to better articulate provenance, production, and process, and then indicating their locally-sourced alternatives.

The significant potential for new jobs, trades, skills, practices, and local economic and social value can also be made clear by conveying the 'halo' of material activities surrounding these prototypes. **Green House** and **Aqua House** indicate the possibility of adapting Australia's existing agriculture and forestry sectors to become the primary supply chains for local construction.

Strategic prototypes develop the quantitative models required to understand this latent capability—*How much stone can be sustainably quarried in Australia? How much reforesting is required? What volumes of existing straw production might be repurposed from agricultural waste?*—as well as producing the *'click in the mind'* associated with qualitative experiences.

> We have not yet reached the stage where the material of cities would grow in environments for which the city would be responsible; cities where the built environment would organically derive from the living matter it takes care of. We have not yet reached that degree of coherence where, in a world where we can build intelligently from the trees produced by our own municipality, it will no longer be necessary to transport and process the wood. This holistic approach is not something from a science fiction scenario… What we still lack is perhaps the capacity to imagine a habitat designed outside the narrow financial and normative channels that currently condition its production.
> Christophe Carsaros (Leloup et al. 2022)

A shift in education and training, and their associated accreditation requirements, can also be better understood and articulated through such prototypes, particularly if they are built as joint projects between industry and academia. There is little doubt that tertiary education will need 'root and branch' redesign in response to the potential of circularity and retrofit. As Material Cultures (2020) note, it has become entirely possible *"to have an extended productive career in architecture without ever coming into contact with the world outside the drawing—the materials and people that drawings command"*. In architecture at least, this culture starts at school.

In response to this, the Master of Architecture programme at the University of Melbourne's Melbourne School of Design (MSD) has reoriented a third of our core design studios around questions of materiality and circularity. Most promisingly, MSD has been collaborating with the University's science faculty at their agricultural campus at Dookie, Victoria, running week-long field trips as part of semester-long architecture studios led by André Bonnice. Here, students learn how to work with bio-based materials directly, constructing building elements from earth, straw, hemp, and timber, drawn from the farm, and producing speculative designs about their systemic possibilities. Teaching activities are complemented with co-curricular public talks around this theme—for example, from Mae-ling Lokko, Fatou Kiné Dieye, Summer Islam, Philippe Rahm, Mio Tsuneyama and Fuminori Nousaku, Indy Johar, Nori Kawashima, Deb Chachra, and Sarah Ichioka, amongst others. A series of similar activities across other disciplines is emerging, and new post-professional courses directly addressing circularity are being developed. Other schools are at various points on this transition and indeed many are further ahead (not least the Royal Danish Academy, who we visited during this project).

All three prototypes, if designed, built, and 'operated' by students, present as learning opportunities, but also signal the future of design, architecture, and construction education.

Green House can also articulate the potential for community-led self-build systems to use contemporary fabrication techniques. The examples of the global Wikihouse movement, VUILD in Japan, and the WeCanMake project centred in Bristol, UK, all indicate the new possibilities for self-build, oriented around open systems as well as locally-sourced bio-based materials. Self-build has a long and rich tradition in Australia, as elsewhere, but is currently a niche activity in comparison to these system approaches.

Blue House will test material innovation as well as building code. It will ask us to calculate the total volumes of existing material that might be usable in Australian cities: so-called *'urban mining'* (or *'urban forestry'* in the case of timber). The Danish *Resourceblokken* initiative explores the use of reclaimed concrete slabs in demolished public building stock, highlighting the strength, durability and qualities inherent in such materials. Whilst the demolition of such building stock can often be avoided, not least in the case of Melbourne's public housing as proposed by OFFICE (2021), where such buildings *are* carefully dismantled their materials can continue to be used, and re-used. Malmö's *Materialbanken* indicates the municipal infrastructure required to support and drive an ongoing life for materials. Van Gerreway (2025b) describes the richly-inventive architectural scene that has emerged in Belgium around these principles (such as Rotor, RotorDC, BC Materials, amongst others).

Insights from this and other prototypes would include sketches of 'end-of-life' or 'extended producer responsibility' legislation for buildings and building elements, which begin to recognise that materials are not at the end of their life at all, but continually valuable, both as components of subsequent buildings or, where possible, returning to the biosphere to regenerate the soil.

Following a mission-oriented innovation framework, strategic prototypes, with their interwoven DNA for spreading and scaling, move to **systems demonstrators**, which are larger scale, more extensive, and more firmly grounded systems, not merely speculating about code and policy but actively attempting to unlock new forms of policy, practice, and associated infrastructure. These demonstrators move experimentation closer still to the mainstream—indeed the aforementioned French Government regulation (RE2020) was framed as *'Experimenting with the construction of tomorrow's high-performance building'*—and ultimately to projects that are actually habitable living systems. As well as numerous small building examples, there are now district development projects—to pick three examples from the Netherlands alone: *Common Woods* in Amersfoort, *The Erven* in Hoofddorp, *Xylino* in Almere—that are being pursued with highly ambitious materials agendas framing what is built, how, and why. Systems demonstrators emerge at these cluster, neighbourhood, or district scales, revealing the wider sectorial, infrastructural and environmental patterns beneath and beyond.

> If you're not designing systems, you're just decorating problems.
> Fatou Kiné Dieye (quoted in Berwick 2025)

Strategic prototypes prepare the ground for systems demonstrators. The sketches here, as notional **Blue**, **Green**, and **Aqua Houses**, each pushing out different edges of the canvas, are proposed as manifestations of the Circle framework, each translating an analytical lens into a built experience, each articulating the systems, material flows, and practices implicated within them.

So, what *would* it mean to say that '*to build is also to grow*'? That a building might make our shared soils healthier, our air and water cleaner, as an outcome of its construction? What if building could be closer to farming than mining, architecture closer to agriculture? How many buildings could be grown locally? How do we stop using more resources to try to solve a resource crisis?

There is one good way to find out.

Refining through making

The introduction noted how additional facets could be added to the Circle framework: assessing the health and wellbeing properties of bio-based materials; the possibility of new jobs, trades, technologies, and industry as part of local economic development; the potential for self-built community-led housing via modular fabrication systems and locally-sourced materials; and the aesthetic and cultural qualities to be revealed by working with these planet-aligned alternatives.

Yet aspects of the existing Circle framework might be immediately be developed. As discussed throughout, Circle is a deliberately high-level initial reading, aiming to provide a directionality that prompts more meaningful questions about materials. Its components are highly complex in reality—for instance, design-for-disassembly is an entire field of variables rather than a single 'score', just as ecosystem impact is clearly a particularly complex assessment across such a diversity of ecologies. Yet with the common sensical clarity that the *absolute sustainability* perspective brings, it is clear to see that certain materials have an essentially irrecoverable impact on ecosystems whilst others do not, just as we can immediately see the difference between a bicycle and an SUV. Circle's approach is to largely side-step *'numerical environmentalism'* (Petersen 2024, 2025) in favour of providing a clear sense of direction to be developed and articulated via strategic prototypes and systems demonstrators.

However, more accurate data about the environmental impacts of material resource flows should be gathered. The activities of the sector are still largely based on *"disparate data sources, limited in coverage to only a fraction of the environmental flows associated with the production of any given material, and difficult or costly to access"* (Crawford et al 2019). Indeed, Circle is largely about highlighting those hidden impacts, potentials and dynamics, as part of related work at the University of Melbourne, such as the Australian Reduction Roadmap and BeyondEPIC platform (https://www.beyondepic.io/). Many of those impacts can, and must, be discovered, assessed, and accurately quantified. Many more complex values must be qualified with good judgement, when it is not possible or meaningful to quantify. Various forms of technology can be brought to bear to aid this, whether remote or local sensing, material passports, autonomous systems, and forms of machine learning, for an industry that is typically behind most other manufacturing-related sectors in these respects. Equally, greater care can and must be taken without the need for the crutch, or distracting cul-de-sac, that technology sometimes provides.

This next section provides reflections on the framework's facets, as signposts for future research and prompts for public discussion. In particular, the areas concerning **emissions**, **ecosystem impact**, **durability**, and **circularity** warrant further investigation, best pursued through prototyping, whereas those of **production scale** and **production time** are bound up in broader questions of demand, need, and supply, themselves worthy of investigation but via subsequent but related projects, as noted earlier. As with our earlier reference point of the Commonwealth Experimental Building System, prototypes can exemplify possible spatial and material outcomes for community, industry, government, and research, as well as making legible new construction systems and material flows.

Emissions
Carbon counting and beyond

The shift in emphasis to embodied emissions is fundamentally important. Operational emissions have been addressed for some decades, and are becoming increasingly easier to manage at least in some new buildings. Therefore, if we can see operational emissions decreasing from buildings over time, upfront embodied emissions assume a far larger increasingly large proportion of total greenhouse gas emissions associated with the buildings.

To complicate this overly simplistic perspective, we must also note that operational emissions are essentially unpredictable in reality, at least from the perspective of initial design and construction. They are in the future, and thus unknowable. A designer does not know whether the wooden window frames specified will be rapidly replaced with unplasticised polyvinyl chloride (UPVC) frames, or how a building's inhabitant might actually use their heating, or whether a home extension made of imported glass and steel frame is added to the local straw and timber original. Some of our industry discussions described how Denmark is having to develop new capabilities for assessing initial building approval, and then ongoing change. Stewart Brand's (1994) line that *"All buildings are predictions. All predictions are wrong"* might be adapted to note that all building lifecycle assessments are wrong too, by definition.

Whereas, from the perspective of a newly-completed building, embodied emissions have already happened, occurring in the upfront production and construction processes. (After Alter (2024), it may be that 'upfront emissions', rather than 'embodied', may be a better way of describing this aspect). This upfront dynamic means, in theory at least, it becomes possible to be *more* precise about our analysis and understanding of associated embodied emissions, not less. The irony is that, as noted by Crawford et al (2019), the sector has little meaningful data on upfront embodied emissions for material lifecycles across supply chains, production processes, construction, disassembly, re-use in 'technosphere' (Haff 2013) or disposal into landfill or regenerative 'biosphere' (Girardet 2022). We will need a significant increase in in-depth research and new tool and infrastructure development in and around design, construction, and material sourcing, as well as new standards and certification, guidelines, regulations, and education and training for industrial, municipal, and craft-based practices and processes, as outcomes of system change. At that point, frameworks like Circle can add further detail to its emissions category, including an assessment of embodied and operational emissions per building and material lifecycles. Circle's high-level visualisations of supply chains and production processes for building elements are effectively a suggestive placeholder to be 'filled-in' with the outcomes of further research in this area.

A single-minded focus on emissions has been understandable, given several decades of emphasis on the need to address anthropogenically-produced climate change. Yet a culture of 'carbon counting' is not only likely to produce what Ormond and Goodman (2015) memorably described as an *"imponderable 'wrongness'"*, but produces a fraught minefield of 'perverse incentives' from a policy perspective: not least the Jevons Paradox-based increase in resource use that often follows incrementalist 'less bad' improvements (Hickel, 2021); a 'kg of CO2e per square metre' assessment can lead to larger, emptier houses appearing to be better options than more compact alternatives; an emphasis on emissions alone can leave the highly optimised processes for 'industry-aligned' materials like steels and concrete appearing to perform better—in this respect—than regenerative bio-based alternatives like timber, and so on. As Fressoz (2025) points out, *"timber has been key in the expansion of suburbs"*; the building material itself may be potentially 'circular from regenerative sources', but if it used to produce patterns of urbanisation that are high-emissions, their impact remains negative.

These 'wrinkles' in the science occur outside of wider considerations that Fressoz's broader work describes: the continuing increase in the volume of resources used, rather than any form of meaningful transition. As noted below, a focus on emissions alone can inadvertently ignore deeper questions about size of building, its typology, the potential creation of alternate infrastructures for bio-based materials, and crucially, an assessment of ecosystem impact caused by material extraction.

So whilst pursuing more accurate, more extensive data about material resource flows before and after building is absolutely imperative, we also need more sophisticated understanding of how to use such numbers—how to critique them as well as deploy them—and what multivariate criteria to complement them with.

> The danger here is that despite commendable commitments and reductions made by nations, global corporations and individuals—given the seemingly inevitable and/or imponderable 'wrongness' in each of these numbers—the result might be that the sum of the parts do *not* add up to the whole. With the ideology of measurement linked to the ideology of action and this new-found emphasis on those quantifiable and disclosed emissions and reductions within a supply chain, we are seemingly side-stepping a more confrontational engagement with the unsustainable consumption practices at the heart of climate change.
> Jim Ormond and Michael K. Goodman (2015)

Emissions refined by prototyping

Prototyping's task is to highlight the flaws in current logics whilst adumbrating the potential in alternatives. Blue House can describe, through both its tangible built outcome and associated communications, the value of re-using existing 'sunk' emissions, and the scale and possibility of 'urban mining' or 'urban forestry'; a system-scale re-imagination of the existing building materials that surround us, reversing the industry supply-side logics of new build towards mass retrofit. Green and Aqua House prototypes conversely highlight the near-term transformation required in the logics of those new buildings required to match societal need. For example, where some well-meaning architects currently argue for the value of high-quality fired brick, based on potential design lives of several hundred years, prototypes must indicate that the key timeframe is the next decades to 2050, before irreversible feedback loops are locked-in. Prototypes must highlight the imperative of the upfront emissions now, rather than their long-term amortisation, as valuable as that may be in other ways. Thus, Aqua House demonstrates the potential in stone to produce, or replace, fired bricks, whereas Green House indicates the potential in farmed materials from extremely low-emission local regenerative sources.

Ecosystem impact
Working with uncertain data

Pace the difficulty of assessing greenhouse gas emissions, it may be even more difficult to simplify an assessment of 'ecosystem impact' as if a coherent, consistent, and easily communicable aggregated 'score'. Yet despite the inherent difficulty of accurate measurement, Circle's contribution is to suggest that ecosystem impact is placed alongside emissions and circularity, as of equal importance in terms of 'planet-aligned' material choices.

Ecosystem impacts of construction range across a wide range of material types and processes, encompassing sand and soil, forestry and farmland, existing building materials and land-use, water and waste, and so on. For example, steel production for buildings is predicated on iron ore extraction, which not only contaminates landscapes but could also involve the destruction of ancient and sacred Indigenous places (MOULD 2025). Even 'planet-aligned' construction elements like timber could involve denuding and destabilising forested hillsides, just as roof-top solar cells require batteries currently drawn from lithium mining which may be contaminating freshwater supplies, as well as quartz, copper and aluminium frames produced from bauxite extracted from open pit mines (Mazzucato and Hill 2024; Malterre-Barthes 2021). Straw and hemp growing could be highly beneficial for soil, if via regenerative agriculture, or highly damaging if practiced via industrialised agriculture. Assessing ecosystem impact is as much about actual practices as theoretical potential. Indeed, once a building is demolished or dismantled, its ecosystem impact continues. The waste footprint of the built

environment sector has already been noted, with construction and demolition waste contributing over 30 per cent of total waste produced (Purchase et al 2021), and 60 per cent of material use and waste generation in the UK (Mant 2019).

> The relentless expansion of urban areas, where wetlands are paved over, forests are clear-cut, and streams are concreted over, disrupts land's natural capacity to regulate climate, moderate temperatures, and absorb rainwater. Large-scale excavation and land alteration disrupt soil structures, leading to erosion and the loss of fertile topsoil. As the soil structure deteriorates, it becomes less capable of supporting plant life, leading to a cycle of decline in land quality and biodiversity. Land is left wounded and barren.
> MOULD (2025)

The impacts on planetary boundaries and living systems are multiple and cascading. Research indicates that the human-made material mass of the 'technosphere'—such as concrete, plastic, asphalt and so on—exceeds all living biomass (Elhacham et al. 2020). The Earth's land surface transformed by mineral extraction and construction is on a scale greater than any natural erosive terrestrial geological processes; for river sediment alone, anthropogenic contribution to production of sediment is 24 times greater than the sediment supplied annually by the world's major rivers to the oceans (Cooper et al 2018). In terms of biodiversity loss associated with this ecosystem impact, WWF estimate a decline of 73 per cent in average size of wildlife populations between 1970 and 2020. These declines, due to habitat loss and resource exploitation, are likely to lead directly to irreversible tipping points in Earth's 'life-support systems' (WWF 2024). The World Economic Forum's *Global Risks Report 2026* finds that biodiversity loss and ecosystem collapse is the second most severe long term risk facing humanity, after extreme weather events (WEF 2026). Both of these risks might be linked to construction, through ecosystem impact and emissions respectively.

Finally, such extractive land use, and its associated degradation, pollution and enclosure, is often embedded in colonial land appropriation and thus questions of ecological and spatial justice (Ghosh 2021; Liboiron 2021; Malterre-Barthes 2025; MOULD 2025).

Little of this presents in greenhouse gas emissions-related reporting, although clearly these impacts are often systemically interlinked. Construction's material demands are at the heart of these processes and so, by implication, are design, architecture, and planning.

Research finds that, despite the emergence of 'biodiversity net gain' criteria at the building scale in some countries, most existing 'green building' rating schemes do not purposefully address ecosystem impact at all: *"the most widely adopted green building rating schemes globally … do not specify biodiversity objectives (85%)"* (Kiss et al 2025). Further, as noted with our redrawing of Brand's pace layers diagram (p.159), a building's ecosystem impact mostly occurs beyond what is commonly thought of as 'the building scale'. Thus biodiversity loss and ecosystem collapse will also occur well outside of the plot that the building sits within. This implies a fundamental reconceptualisation of building as momentary assemblage within broader material flows, yet the fact that 'green' rating schemes do not even coherently assess biodiversity at the building scale indicates the scale of the challenge ahead.

As with emissions, attaining accurate data for ecosystem impact within a coherent framework should be a priority for subsequent research. Yet given the urgency required to transform systems, it may be important to pursue exploratory and engaged practices for positive ecosystem impact in line with 'absolute sustainability', underscored with a planetary boundaries, irrespective of having complete and coherent data 'in advance'. In other words, how do we take action without the depth, breadth, and veracity data we might ideally want?

There is emerging understanding of how to work with *"flawed, uncertain, proximate, and scarce data"* (FUPS) even in ethically-complex and highly sensitive research environments such as child mental health (Wolpert and Rutter 2018).

> Datasets that can be considered FUPS are likely to exist in many domains of complex and dynamic healthcare systems. There are clearly dangers of over-interpretation of such data, but there may also be dangers of non-use, which allow stakeholders to use the FUPSness of the data to ignore potentially important but uncomfortable findings and hypotheses …Debates in complex healthcare systems take place within existing, highly charged discourses involving hard cores of interpretation formed over many decades. FUPS data are clearly disputable facts, but they can be drawn on as a form of evidence to aid decisions in the swampy lowlands of practice.
> Miranda Wolpert and Harry Rutter (2018)

Wolpert and Rutter outline a set of useful heuristics for working with *FUPSy* data, such as seeing *'data as a partial remnant'*, ensuring data *'follows principles of transparency and clarity'*, and constantly *'triangulating data'*. These, and other principles, with the caution necessary of their context, provide ways of working with FUPSy data nonetheless. Further Circle-oriented research might use an understanding of the *"FUPSness"* of data in the equally swampy lowlands of architectural practice, regarding ecological impact.

Design's tightrope-walks between art and science, between proposition and reflection, between making and learning, might well lend itself to such an approach. Similar conclusions might be drawn from social innovation practices, and particularly the systems change methods summarised by Farley et al (2021). They discuss working in socio-political contexts that are *"diffuse, messy, and ambiguous, entailing multiple pathways", "learning and identifying and building on local knowledge", "adaptive explorations", "no defined time-line nor pre-defined end-states, with shared visions guiding ongoing learning", "managing risk by making smaller bets", "shaping (locally possible) probabilities (that) can be scaled"*, improving *"local decisions…meaningful progress"* and refining *"assumptions about social context."*

These principles are also redolent of Wolpert and Rutter's practices, and entirely in line with contemporary strategic design methods (Hill and Melander 2025).

These sensibilities undercut the false certainties of 'numerical environmentalism' (Petersen 2024, 2025). They draw from broader critiques of scientism, such as those of McGilchrist (2019), who notes that the models by which we bring our attention to bear on the world *"changes the nature of the world we attend to, the very nature of the world in which those 'functions' would be carried out, and in which those 'things' would exist"*.

McGilchrist's work suggests that these limits do not entirely invalidate the notion of, say, attempting to numerically evaluate emissions or ecosystem impact; just that such abstractions cannot 'capture' anything like a complete understanding of material systems and cultures, and it is highly dangerous to assume that they might.

> But I do think that things as they exist in practice in the real world, rather than as they exist in theory in our re-presentations, are likely to be intrinsically resistant to precision and clarification. That is not our failure, but an indication of the nature of what we are dealing with. That does not mean we should give up the attempt. It is the striving that enables us to achieve a better understanding, but only as long as it is imbued with a tactful recognition of the limits to human understanding. The rest is hubris.
> Iain McGilchrist (2019)

A holistic, re-integrated approach, humanely eliding art and science, might more meaningfully recognise the complexity of material cultures: ongoing quests for the precision implied by scientific frameworks alongside a humble recognition of their limits, with their FUPSy *'data as a partial remnant'*; a re-valorisation of knowledge and judgement drawn from experience balanced alongside the usefully transferable abstractions of numerical quantities.

Design disciplines are predicated on such integration, frequently shifting lenses between analysis and synthesis, between the fixities drawn from the technical assessments of scientists and engineers and those flowing, animated, embodied and poetic perspectives of a whole, to allow for a *"new Gestalt"* (McGilchrist 2021).

> My relationship with the materials is necessarily different from that of the scientist or the engineer. I am always keeping the larger project in mind. The scientist is concerned with specific analyses, whereas my role is to interpret and synthesize this diverse information and apply it strategically. My role is curatorial. Scientists, as collaborators, provide me with specialized knowledge. Their contributions enable me to sense the existing materials in deeper ways than I would normally be able to. Specialized expertise permits me to feel inside the body of the site, to learn about possibilities from its hidden interiors that would otherwise remain opaque to me. I am then able to elevate or scale up some of these elements, as patterns or structural prospects emerge.
> Søren Pihlmann (Dickinson & Pihlmann 2025)

Better assessing ecological impact will require this precisely this curatorial perspective, weaving together inputs from ecologists and engineers alongside those of others, to *"feel inside the body of the site"*, working directly with *"flawed, uncertain, proximate and scarce data"* alongside the richness of embodied interaction, and to articulate the multiple properties of material ecosystems via propositional design practice.

> There are, it seems to me, four main pathways to the truth: science, reason, intuition and imagination. I also believe strongly that any world view that tries to get by without paying due respect to all four of these is bound to fail. Each on its own has its virtues and its vices, its gifts and its inherent dangers: only by respecting each and all together can we learn to act wisely.
> Iain McGilchrist (2021)

Ecosystem impact refined by prototyping

Core to strategic design approaches exploring how to work with FUPSy data in the context of complex systems, prototyping is a vehicle for discovering, understanding, and refining data, learning through doing. Data emerges as a 'vapour trail' following prototypes, rather than a precursor for embarking on a project. All three prototypes suggested here must be produced through the transdisciplinary design process imagined above, combining engineering, material science, social sciences, curatorial perspectives, design disciplines, and others. A university, with its diversity of disciplines co-located, provides an ideal partner for this form of prototyping, alongside other multidisciplinary partners, whereas the importance of a grounded, participative, and place-based approach can move towards the *'new Gestalt'* suggested by McGilchrist above.

Circularity
Higher up the R-Ladder

Largely agreed-upon core principles of circularity appear to be clear. The Netherlands Environmental Assessment Agency PBL describes the 'R-List' (Potting et al 2015)—sometimes 'R-Ladder'—as a coherent holistic approach, in particular by emphasising the *"more ambitious"* 'Refuse/Rethink/Reduce' short loop principles. These accord with absolute sustainability's subtraction or simplification strategies (Mossin et al 2023), in line with the 'paradigm changing' leverage points in Meadows's framework for systems change (2008). Yet other circularity strategies often conveniently ignore these principles, concentrating instead on the recycling-oriented measures at the bottom of the ladder, which are less like to have the scale of impact required. As PBL note: "*Recycling alone, and low-grade recycling in particular, is still closely related to a linear economy"* (Potting et al ibid), just as Hajer and Oomen (2025) see that relying on a bundling of unproven carbon dioxide capture, removal and storage technologies into net-zero goals are *"simply empty promises to keep an extractive system exactly as it is—to forego any of the hard choices that need to be made"*.

To attain these short loop higher R-values of Refuse/Rethink/Reduce, Reike et al (2017) propose that, *"government and policymakers have a key role in enabling mechanisms for shorter loop value retention options, setting targets, and in directing economic activities towards more circularity".* This echoes our conclusion regarding the role of public code, public procurement, and public prototypes.

Where most bodies agree on circular principles, in the context of construction at least, is around the core concepts of working with bio-based materials from local regenerative sources or recycling of existing materials, design for disassembly, material passports, enhanced producer responsibility, and so on. Each of these has had little traction in the built environment sector thus far, just as recycling practices and systems in general appear to be largely ineffective, at least in sufficient volume, and even when incentivised to do so (Savini 2025).

Design-for-disassembly is well-understood in principle, and demonstrated throughout many of the projects mentioned in this report—including the 1300 year-old Ise Temples (Adams 1988). Yet it is rarely mandated coherently or at all, and is thus far from mainstream practice. End-of-life producer responsibility is similar: increasingly implemented in other sectors, yet it barely exists in construction. Local sourcing of materials is possible, yet also rarely mandated or incentivised, and in Australia at least does not tend to figure in policy discussions about planning and building. Practices of care will require transformation in business models and civic priorities. Forms of material passport will be necessary to support the traceability and legibility of circular practices, including for local sourcing, transfer to another aspect of the 'technosphere', or return to 'biosphere'.

Yet there are no national protocols or platforms in place. For example, Rousseau et al (2025) find that, "*Contrary to what prevails in many other commodity-based industries, no certification distinguishes green concrete products from non-green equivalents"*. Even highly used materials like imported timber are often effectively untraceable in practice, despite many decades of international attempts at certification. Studies find that half of Australia's imported timber fails traceability testing whilst other surveys indicate 90 per cent of Australians surveyed want to see clear Country of Origin labelling on mainstream timber products (Ross 2026).

There are techniques and processes to rediscover, invent, and refine in all these aspects, and it will require the 'dark matter' of regulation, policy, and standards to hold the industry to account. Prototypes can embody 'the code we need', rather than the one we have, and can convey these immaterial aspects via integrated communications, as discussed earlier. Materially and spatially, prototyping can demonstrate how the particular 'planet-aligned' set highlighted in this initial Circle work, chosen for their ubiquity and relative ease-of-use, could quickly and easily be extended to highlight the potential in other existing 'everyday' materials, such as bamboo, wool, or seaweed, or the many novel bio-based materials in development.

Such bio-based materials can enable subtraction strategies that can reduce overall material volume in buildings, moving towards the higher reaches of the PBL's R-Ladder. Given its greater impact, Circle's representation of circularity will need to explicitly measure, and foreground, this potential to 'reduce' or 'refuse'. For example, improving insulation can frequently obviate the need for complex, weighty HVAC systems (Mossin et al 2023). This could be achieved by straw cassette wall systems as much as, or alongside, other 'passive design' approaches. The Hyllie building in Malmö reduces the need for concrete via its timber core and straw-based wall system, just as the straw cassette frames reduce the amount for timber required in that envelope. The Xylino building in Almere requires no concrete core due to its lightweight modular timber construction.

Prototypes can indicate the potential in newer materials, helping to overcome the barriers described earlier—**relative advantage, complexity, compatibility**—and directly aiding with **trialability** and **observability**. These might include mycelium, microalgae, seagrass such as eelgrass thatch, bamboo and bamboo-based composites, bacterial substitutes for cement like BioMason, blue biomass elements for facades (as pictured). These have material and spatial qualities that pose cultural questions as much as performative aspects. Other materials, such as the compressed stabilised earth blocks explored by Studio Suddo Neuve (2025) or the stone bricks and beams of Future Observatory's Stone Demonstrator (2025), or indeed combo nanocellulose in cement (Naseem and Rizwan 2025), may be closer to existing material expectations, and here prototypes might emphasise their performance outcomes.

From a research point-of-view, the more intransigent building elements—those difficult to easily replace with obvious bio-based alternatives, such as glass and plastics—would be worth foregrounding in prototypes. Emerging research indicates the potential of bio-based replacements for polyester resins, widely used in fibreglass composite structures (boats, some motor vehicles, small buildings) as well as epoxy resins used in adhesives and high-performance composites found in sports equipment and industrial components. Researchers at University of Oulu have developed a biomass-based polyester resin, produced with cellulose and hemicellulose found in lignocellulosic biomass in forestry and agricultural side streams (Terho et al 2026). This novel material has *"76% higher tensile strength than a commercial fossil-based polyester resin"* (Sustainable Chemistry Research Unit 2026). For near-term cost-effectiveness, these might be produced using existing chemical industry production lines, just as our existing agricultural and forestry infrastructures and practices might be adapted for materials like local timber, straw, hemp, stone, and earth, at scale.

As Melbourne's bio-economy incubator Co-Labs makes clear, a mission- or challenge-led approach is able to align national scale research and innovation funding and resourcing programmes—such as USA's SBIR, UK's Biomedical Catalyst, and EU's Horizon Europe program—with activity on the ground, in the form of products, projects, platforms, and places (Wines 2026). However, only in the EU's New European Bauhaus initiative do we see a dedicated

BioLocal: Blue Biomass for the Construction Industry Queensland University of Technology, with Henning Larsen and Centre for Information Technology and Architecture, Royal Danish Academy (2025)
This research project investigates the potential of utilising residual sludge from wastewater purification processes as a low-carbon bio-based material. The project develops a building façade system that promotes biodiversity by creating habitat and improving local microclimates. Façade modules are constructed using additive (3D-printing) and traditional manufacturing techniques.

focus on the materiality of the built environment—despite construction being the largest global source of greenhouse gas emissions, waste, and ecosystem degradation—and here too the emphasis has been placed on place-based prototypes and systems demonstrators.

Circularity refined by prototyping

All three prototypes should exemplify design-for-disassembly, agreements and systems for end-of-life producer responsibility. Designed as kit-of-parts approaches, novel bio-based materials should be able to be integrated into the prototypes over time, replacing existing circular materials. inspired somewhat by Alvar Aalto's Muraatsalo 'Experimental House' (1960) or indeed the Commonwealth Experimental Building Station (Miller-Yeaman 2022). This sees the prototypes a *"a vehicle for the continual and ongoing process of framing, asking and testing of a portfolio of research and innovation questions and actions … places to hold and pursue research questions, but also contestation and dialogue, as well as enabling change on the ground"* (Hill 2022). Finally, although a core value of built prototypes is their tangible physical and spatial presence, the prototypes must also find a way to convey the volume, and impact, of materials not used—the Refuse/Rethink/Reduce aspects of the R-List—through either integrated installation or communications alongside.

Durability
The cello and the garden

Noting that durability often provoked the greatest discussion in discussions, we propose two lines of enquiry for enriched understanding of durability in the context of biomaterials: *the cello* and *the garden*.

The CELLO, as a metaphor, draws from an observation that some of the oldest designed objects still in daily use are musical instruments. For example, the Australian Chamber Orchestra routinely uses string instruments that are 300-400 years old, and with their core structures largely constructed from biomaterials like wood, with other aspects often animal products. They are insured for millions of dollars, highly prized by their performers, and as 'tools' are continually capable of adapting to innovation in music.

Through this care for its materials, the instrument *gains* in value, performance, and cultural meaning:

> Every cello eventually takes on the character of its player. The resonance of the wood alters, just a little, when an instrument is repeatedly played in particular ways. After thousands of hours of practice in the hands of one owner, it is not the same instrument. It takes on the imprint of its player like a finger in wax, and is shaped by their partnership, just as its strengths and weaknesses will dictate how the cellist plays … Any cello with a history hums with audible ghosts; but a new cello is a tabula rasa, with no history to hold, no memories in its sound, no repetitious practice inscribed on its body.
> Kate Kennedy (2024)

Although some components of these instruments, like strings, are continually being replaced—almost akin to the Plato's retelling of the *Ship of Theseus* story, whereby a continual replacement of every element of the ship over time, at some point poses the question of whether 'the original' ship still exists—the instrument's overall form, function, and some of their core structural elements, such as the wooden bodywork, remain unchanged for centuries. (As Martínez de Arbulo (2023) points out, this more complex patterning of preserved and replaced is actually closer to the dynamics of much traditional architectural conservation than the *Ship of Theseus* myth implies).

Rarely does such an instrument end up in landfill. The cello metaphor suggests a building that is composed of durable, largely unchanging biomaterial layers, which maintain this durability through care, and which grows in value over time as a result. This requires material stewardship for subsequent generations, beyond the lifespan of individuals. It foregrounds a preservationist approach to care, whilst still allowing for some minor adaptation and replacement. It recognises that biomaterials can be highly durable, and present as slower moving layers, when cared for by attentive users. The analogue to an architecture for ongoing careful renovation seems clear.

> Old buildings hold a unique charm with fewer modern materials and plastics used, preserving handmade components that are mostly unavailable nowadays. The atmosphere which reflects the construction practices, lifestyles, and values of times past is imbuing a depth in time that new constructions cannot replicate.
> Fuminori Nousaku and Mio Tsuneyama (2024)

The GARDEN, as an alternate metaphor, recognises a system that is constantly changing through engagement. It does not attempt to preserve individual elements, or even an overall plan or form, but remains vital, thriving, productive and regenerative through engagement and care. Elements come and go, based on patterns of habit, need and desire, but also of seasonality, and complex interactions with wider systems of climate, biodiversity, and landscape. The system has a disorderly slowness.

Derek Jarman, reflecting on his garden at Dungeness on the east coast of England, wrote that a garden *"connects you to the future. When you don't know how much time you have left, that sense of planting something that will flower next summer is immensely sustaining"* (Jarman 1991). As opposed to the cello's permanence through preservation, the garden moves through time, adapting to changing circumstances. So durability with the garden is at system-level, rather than in particular instances or moments. Its continued existence is based on change, perhaps as with the aforementioned temples at Ise in Japan (Tange 1965). The adaptive qualities of the garden allows for significant transformation as well as incremental improvement, through practices of caretaking (Petersen, 2025).

> The garden's profile, constantly changing, depends on its caretaker, and not on an architectural plan, produced on a drawing table.
> Gilles Clement

The constant adjustment of gardening has parallels with those of operational sustainability pursued by 'tuning' a building as if an instrument, or *'sailing a building'* as if a boat (Bordass et al 2025). Elements come and go, and as with almost all gardening, the building's materials can return to the biosphere, rather than remaining in the technosphere.

This form of engagement indicates a shift in perspective for all involved in buildings, including inhabitants as much as industry. In our research discussions, those respondents working with biomaterials noted that materials like straw cassettes, hemp blocks, or timber structures do not significantly increase maintenance requirements. Yet as Petersen's work indicates, care of such materials *will* be foregrounded not only for users but also for designers and architects, builders, and product manufacturers (Petersen 2025). An unsealed rammed earth interior wall may require its carer (the resident) running a wet cloth along the floor edge every few weeks, to wipe up the inevitably accumulating 'dust'. These small acts could be framed as positive relationships between living humans and living materials, tiresome chores, or maintenance costs. Planet-aligned outcomes will thus require engagement by policymakers, regulators, financiers, and developers in turn. The metaphor of gardening does allow us to imagine a reframing of *maintenance* as *care*, to re-conceive cost as value or investment, to see the 'chores' of building upkeep as if akin to gardening, tuning, and sailing instead.

Of course, these perhaps romantic perspectives cannot be removed from questions of social and spatial justice, as Petersen makes clear, drawing on the work of Tronto (2015) and other feminist scholars and practitioners, just as gardening as an activity for necessary subsistence crops is entirely different to gardening for leisure. As Tronto makes clear, the political question of *'Who cares?'* must be to the forefront when imagining new forms of human relationship with buildings and materials.

Circle / **Conclusion** / Prototyping

Durability refined by prototyping
Green House (straw, hemp, timber) most clearly embodies garden-like principles, being composed of biomaterials from regenerative sources that can return to the biosphere, and foregrounding continuous adaptation through its lightweight self-supporting modular construction elements. Blue House (slab concrete) describes our current predicament to some extent. Its steel and concrete elements could be recycled, but the rarely are in practice. Aqua House (stone and timber) is more akin to 'the violin', metaphorically —likely to be cared for, foregrounding ongoing utility via formal utility and attractive materiality, perhaps as per Georgian terraces—stone buildings that have elegantly adapted to cultural change, lasting hundreds of years (given stone's inherent durability), and with some minor elements being replaced over time.

Production scale and time
Beyond the building

Finally, although prototypes might more obviously emphasise the above aspects of Circle framework, they can also foreground broader questions about production scale and production time (and thus cost), each of which could be conveyed through communications around the built prototypes.

These would include those elements outlined in Australian Reduction Roadmap (Crawford et al 2025), concerning more accurate assessment of needs-oriented tenures, changes in fiscal policy, average size of building in relation to demographic shifts, renewable energy infrastructure for production, retrofit versus new build, and so on.

Circular material production scale and speed could be reframed to include assessments of national stocks of strategic bio-based building materials, particularly in the context of security and resilience. The Australian Government's *2024 Infrastructure Market Capacity Report* (Infrastructure Australia 2024) currently assesses supply in terms of 'critical delivery risk'. Yet this is largely based on fixed demand projections as opposed to any stated concern for 'assigned share' of the safe operating space, or equivalent. Whilst some inferences may be drawn for 'planet-aligned' materials—for instance, noting that quarries for stone appear to be relatively well-stocked, based on Victorian and Queensland Government assessments—the report contains only brief reference to innovative construction methods, in terms of 'green steel' and 'green concrete'. Extensive literature reviews by Rousseau et al (2025) indicates how the sustainability assessments of 'green concrete' are highly limited, particularly when examined in terms of ecosystem impact (specifically the *"sand and aggregate crisis"*) as well as social aspects.

Nor does the Market Capacity Report take into account demographic shifts which point to a reduced need for new buildings, given that global population levels are predicted to peak and start declining after 2060s (well within the typical lifespan of a new building constructed today) and with a majority of countries already past their peak population levels (Dorling 2020). New buildings will be needed—clearly, not all existing buildings can be retrofitted to meet new needs—yet there is little sense here of a strategic and planet-aligned 'material budget' with which to build them.

Research on the Danish building sector, framed from an *absolutely sustainability* perspective (Horup et al 2025), is more carefully assessing the carrying capacity of land required to produce bio-based materials for buildings, the potential rate of production, and its land-use impacts, shaping demand and supply symbiotically. The research finds that only through reducing construction, alongside allocating greater land-use to particular materials—*"fast growing biobased materials such as grass, hemp and straw as these materials have lower land use impact"*—can the sector's impact be pulled in line with targets, even taking into account technological advancements.

> By testing lower construction activity and moving away from conventional building materials towards biobased materials we showed that if reduction activity was reduced with around 80% and 50% of the remaining square meters were biobased buildings, then the target for climate change, land use, freshwater eutrophication and resource use metals/minerals would be met.
> Horup et al (2025)

Research by Hansen et al (2025) underscores this material strategy, finding that locally-sourced Danish straw and grass production can complement and counteract the lack of timber supply, local and otherwise: *"using fast-growing biobased materials in wooden buildings is a viable strategy to reduce the requirement for land and to increase CO2 storage in the production stages"*, and that *"building designers and planners should prioritize incorporating fast-growing biobased materials in wooden buildings to replace non-loadbearing products. Essentially, this helps reduce the obvious trade-off between land-use and climate change regarding timber buildings"*. In this scenario, a different form of production time must also be considered, more akin to the seasonal patterns of regenerative agriculture than traditional manufacturing.

Working within planetary boundaries will require this more sophisticated form of 'stock-taking'. The importance of local material security is only reinforced by the disruptions in supply chains witnessed in recent years, due to events like climate change-induced 'extreme weather' and pandemics (Whittle 2020), or geopolitical security issues

Finally, the consistent, large-scale volume that industry usually requires to warrant investment in production innovation is essentially at odds with circularity's imperative for reduction. Fundamentally rethinking what we mean by volume, and thus production scale, is a form of innovation in itself.

> From a planetary perspective, our concern should not be on how to make the first sustainable solution, but on how to repeat it—a kind of 'large-scale sustainability' made possible by many small, tweaked actions combined in a way that allows us to subtract rather than add resources. For an innovation to be truly successful, it needs volume
> Mikkel Thomassen (in Mossin et al 2023)

Prototypes must embody and convey this different sensibility for production scale, producing the 'volume' of a transformed built environment, relatively rapidly, and yet with fewer resources used overall.

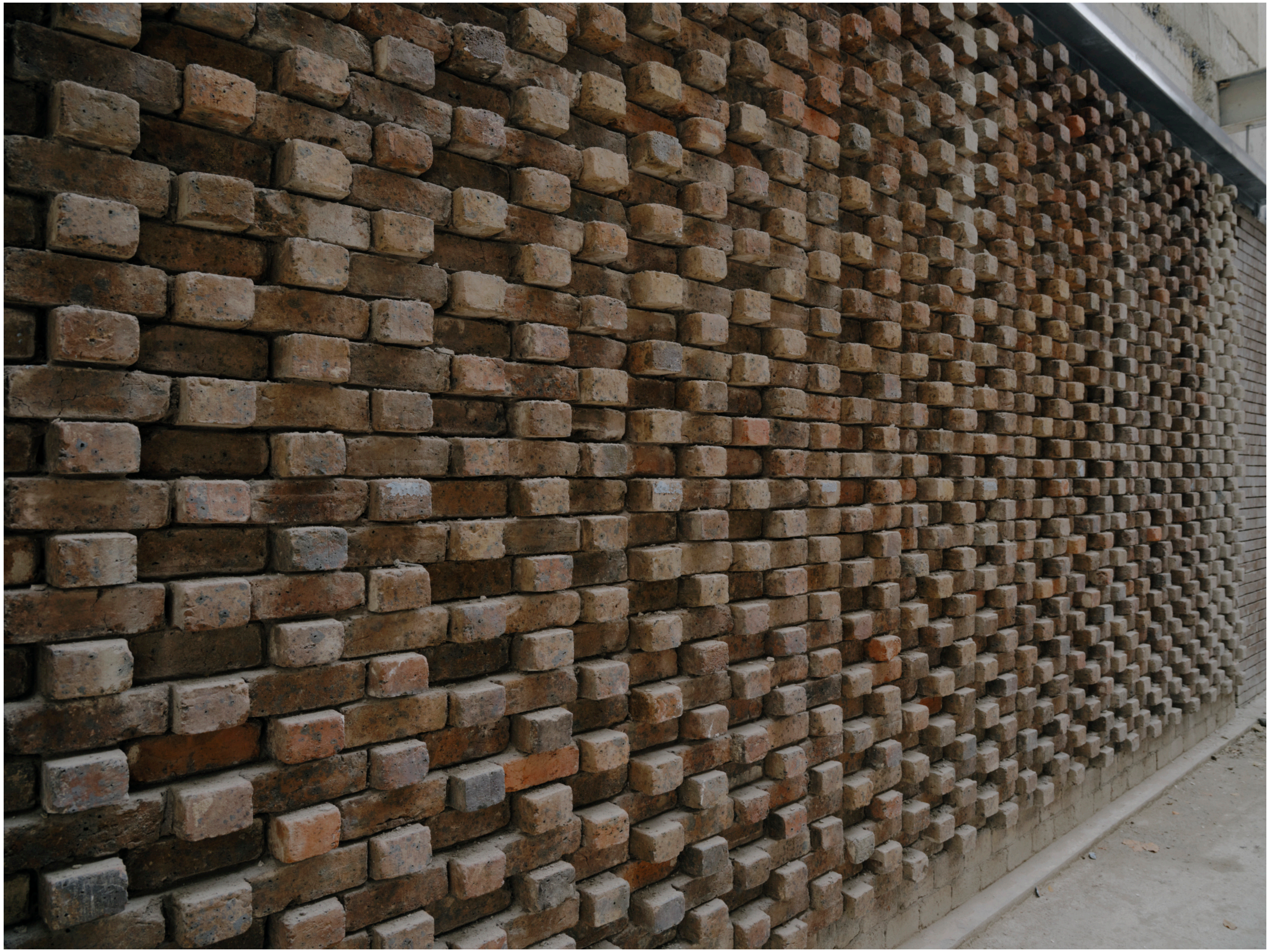
Production scale and time refined by prototyping
Circle's proposed prototypes could convey this integration of concerns: of production scale, with the differing production time of crop-based and other bio-based materials, along with scale, form, typology, and dynamic of building, and building elements.

Summary

The façades of Alvar and Elissa Aalto's **Muuratsalo 'Experimental House'** (1953) were designed with 50 panels, allowing for many different types of brick and ceramic tiles to be continually tested in situ. Its woodshed was built to accommodate tests on load-bearing wooden columns without foundations. Aalto saw it as *"a combination of a projected architect's studio and an experimental centre for carrying out experiments"* (Aalto 1953). At the same time in Australia. the **Commonwealth Experimental Building Station** provided a similar 'chassis' for research and innovation. Research was oriented around cost-efficient steel and concrete fabrication, almost solely for individual home ownership. Yet it also produced the country's first national building standards (Miller-Yeaman 2021) and early publications on building with earth (Goldlust 2023)

Ultimately, Circle suggests a rediscovery of public prototyping platforms in Australia, but directed towards making tangible planet-aligned material flows, whilst refining its analytical frameworks alongside. New techniques and technologies can be continually explored via prototypes, helping to shift perceptions and assumptions about what buildings are made of, and what they might be. They would allow partners to pursue the many open threads described here, as a way of producing richer, deeper understanding into the potential of a regenerative construction sector.

Master Builders Victoria headquarters, Melbourne Fieldwork (2025)
Original feature brickwork, previously concealed behind plasterboard partitions as part of the 1989 renovations, has been reconditioned and revealed.



Reading list

The history of architecture and construction is punctuated with key texts that inform the position that Circle, and initiatives like it, is taking. They stretch back to the first writings on architecture and building, but would also include particularly rich seams of thinking and practice from the mid-1960s to the mid-1970s—from Rachel Carson's *Silent Spring* to EF Schumacher's *Small is Beautiful*—as well as numerous examples of continual invention, activism, and engagement from those outside 'business-as-usual' in the sector, for many decades either side of that period.

The reading list presented here is a more recent survey, sharing writing that influenced this project at this point (December 2025), and is offered up a set of starting points for those interested to follow their interests—in the people and practices behind the text, as well as the works themselves. Clearly, it is not attempting to be complete in any way, but it does suggest the flowering of interest and activity around these new and old directions.

Baker-Brown, D. (2024) *The Re-Use Atlas: A Designer's Guide Towards a Circular Economy*
Bauhaus Earth (2026) *Bauhaus Earth Toolkit*
Boelen, J. et al (eds.) (2023) *Bioregional Design Practices*
Bonnice, A. and Jankovic, A.(2024) *Notes from a finite world: A study of post-carbon paradigms for architecture*
Bordass, B., Pender, R., Steele, K., & Graham, A. (2025) *Learning to sail a building: a people-first approach to retrofit*
Chachra, D. (2023) *How Infrastructure Works*
Crawford, R. et al, (2025) *Australian Reduction Roadmap*
Lewis, P., Tsurumaki, M., & Lewis, D.J. (2022) *Manual of biogenic house sections*
Hill, D. and Mazzucato, M. (2024) *Modern Housing: An Environmental Common Good*
Malterre-Barthes, C. (2025) *A Moratorium on New Construction*
Material Cultures (2020) *Material Reform*
Meredith, M. (2025) *Smaller Architecture*
Misselwitz, P. and Organschi, A. (2024) *Toward Re-Entanglement: A Charter for the City and the Earth. Bauhaus Earth Essays 1*
Mossin, N., Beim, A., and Hau, I. (2023) *Innovation of Nothing: The Capabilities Needed To Lead Sustainable Change in the Built Environment*
MOULD (2025) *Architecture is Climate*
Nousaku, F. and Tsuneyama, M. (2024) *Urban Wild Ecology*
Reduction Roadmap (2024) *Beyond the roadmap: A transition plan for the Danish building industry*
Petersen, T.L. (2025) *Practicing Architecture with Care: An Investigation into Architectural Strategies and Environmental Perspectives Beyond Metrics* (Unpublished PhD Thesis, Royal Danish Academy)
Pihlmann, S. and Dickinson, A. (2025) *Making Matter What Too Often Does Not Matter*
Shinohara, Yuma, and Andreas Ruby, eds. (2022) *Make Do With Now: New Directions in Japanese Architecture*
Space Caviar, eds. (2021) *Non-Extractive Architecture: On Designing without Depletion, Vol. 1.*
Studio Suddo Neuve (2025) *Back to Earth: Urbanization without Depletion. Bauhaus Earth Manual 1*

References

Aalto, A. 1953. '*Koetalo, Muuratsalo*', *Arkkitehti* 9–10/53

Adams, C. 1998. *Japan's Ise Shrine and Its Thirteen-Hundred-Year-Old Reconstruction Tradition. Journal of Architectural Education*, 52: 49-60. https://doi.org/10.1111/j.1531-314X.1998.tb00255.x

Alter, L. 2024. *The story of upfront carbon: How a life of just enough offers a way to a zero-carbon society*. New Society Publishers.

Aouf, R. S. 2024. *First full-height timber wind turbine opens in Sweden*. *Dezeen*, 29 January 2024. Available at: https://www.dezeen.com/2024/01/29/first-full-height-timber-wind-turbine-opens-sweden-design-news/ (Accessed 16 January 2025)

Amies, L. 2025. *Australia's reduction roadmap calls for a 99 percent cut in new housing emissions*. *ArchitectureAU*, 28 Oct 2025. Available at: https://architectureau.com/articles/australias-reduction-roadmap-calls-for-a-99-percent-cut-in-new-housing-emissions/ (Accessed 14 January 2026)

Auburtin, P., Saadé, M., Manthey, M., Louërat, M., Bleyer, J, Martin, J., Baverel, O. 2025. *'Stone masonry floor systems for low environmental impact structures'*. *Journal of Building Engineering*, Volume 113, 2025, 114017, ISSN 2352-7102, https://doi.org/10.1016/j.jobe.2025.114017.

Australian Bureau of Statistics. 2023. 'Average floor area of new residential dwellings'. Published at abs.gov.au, 12 April 2023. Available at: https://www.abs.gov.au/articles/average-floor-area-new-residential-dwellings (Accessed 22 January 2026)

Baker-Brown, D. 2024. *The Re-Use Atlas: A Designer's Guide Towards a Circular Economy*. RIBA Publishing.

Bauhaus Earth. 2026. *Bauhaus Earth Toolkit*. Available at: https://bauhausearth-toolkit.com (Accessed 4 February 2026)

Berwick, B. 2025. 'Fatou Kiné Dieye: "If you're not designing systems, you're just decorating problems"'. *ArchitectureAU*, 15 April 2025. Available at: https://architectureau.com/articles/Fatou-Kine-Dieye-if-youre-not-designing-systems-youre-just-decorating-problems/ (Accessed 3 February 2026)

Bonnice, A. and Jankovic, A. 2024. *Notes from a finite world: A study of post-carbon paradigms for architecture*. Alastair Swayn Foundation. Available at: https://alastairswaynfoundation.org/research/notes-from-a-finite-world-a-study-of-post-carbon-paradigms-for-architecture-2 (Accessed 14 January 2026)

Bordass, B., Pender, R., Steele, K., & Graham, A. 2025. *'Learning to sail a building: a people-first approach to retrofit'*, *Buildings and Cities*, 6(1)

Boyer, B. and Hill, D. 2013. *Brickstarter*. SITRA, Helsinki

Brand, S. 1994. *How Buildings Learn: What happens after they're built*. Viking Press

Brejnrod, K.N., Kalbar, P., Petersen, S., Birkved, M. *'The absolute environmental performance of buildings'*, *Building and Environment*, Volume 119, 2017, Pages 87-98, ISSN 0360-1323, https://doi.org/10.1016/j.buildenv.2017.04.003.

Butler, J. 2025. *'Westminster Council launches Retrofit First city plan'*. *Architect's Journal*. Available at: https://www.architectsjournal.co.uk/news/westminster-council-launches-retrofit-first-city-plan (Accessed 14 January 2026)

CEDA. 2025. *Size matters: Why construction productivity is so weak*. CEDA, ISBN: 0858013657

Chachra, D. 2023. *How Infrastructure Works: Inside the Systems That Shape Our World*. Penguin Random House

Circle Economy. 2023. The Circularity Gap Report: Denmark. Available at: https://www.circularity-gap.world/denmark (Accessed 15 October 2025)

Crawford, R. H., Stephan, A., And Prideaux, F. 2019. *Environmental Performance in Construction (EPIC) Database*. The University of Melbourne, Melbourne

Crawford, R., Helal, J., Hill, D., Stephan, A., Reinmuth, G., Schork, T. 2025. *Australian Reduction Roadmap*. Available at: https://reductionroadmap.au/ (Accessed 14 December 2025)

Climate 360 (2025). *'ClimateRelay Series 1: Building, Episode 1: The road to Paris is steep'*. Podcast episode available via https://climate360.com.au/#episodes (Accessed: 12 January 2026)

Cooper, A. H., Brown, T. J., Price, S. J., Ford, J. R., & Waters, C. N. 2018. *Humans are the most significant global geomorphological driving force of the 21st century. The Anthropocene Review*, 5(3), 222-229.

Dorling, D. 2020. *Slowdown: The End of the Great Acceleration—and Why It's Good for the Planet, the Economy, and Our Lives*. Yale University Press.

Driessen, E. and Grönlund, E. 2024. *Circular concrete scenarios and their environmental impacts: A life cycle assessment modelled after a Swedish city. Journal of Cleaner Production*, Volume 485, 2024, 144348, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2024.144348.

Duffy, F. 1992. *The Changing Workplace*. London: Phaidon Press.

EcoCocon. 2024. Published on ecococon.com website, 13 December 2024. Available at: https://ecococon.eu/ro/blog/2024/how-ecococon-straw-wall-panels-redefine-building-at-every-size and https://ecococon.eu/about/company (Accessed: 14 January 2026)

Elhacham, E., Ben-Uri, L., Grozovski, J. et al. 2020. *Global human-made mass exceeds all living biomass*. Nature 588, 442–444. https://doi.org/10.1038/s41586-020-3010-5

Ellen MacArthur Foundation. 2021. *The butterfly diagram: visualising the circular economy.* Available at: https://www.ellenmacarthurfoundation.org/circular-economy-diagram (Accessed 18 January 2026)

Ellen MacArthur Foundation. 2016. *The circular economy and the promise of glass in concrete.* Published by Google and Ellen MacArthur Foundation on 30 September 2016. Available at: https://www.ellenmacarthurfoundation.org/articles/the-circular-economy-and-the-promise-of-glass-in-concrete (Accessed 18 January 2026)

Farley S, Rose A, Seelos C. 2021 *'The 'Thou Shalt Nots' of systems change'*. *Stanford Soc Innov Rev*. https://doi.org/10.48558/0BXX-MP20

Fressoz, J.-B. 2025. *More and More and More: An All-Consuming History of Energy*. Allen Lane/Penguin

Fukuyama, F. 2014. *Political order and political decay: From the industrial revolution to the globalization of democracy*. Macmillan

Future Observatory. 2025. *'The Stone Demonstrator'*. Published on Future Observatory website. Available at: https://futureobservatory.org/programme/exhibitions/low-carbon-housing-stone-demonstrator (Accessed 23 December 2025)

Ghosh, A. 2021. *The Nutmeg's Curse: Parables for a Planet in Crisis*. Chicago: University of Chicago Press

Girardet, H. 2022. *'Biosphere and Technosphere', The Ecologist*, 28 November. Available at: https://theecologist.org/2022/nov/28/biosphere-and-technosphere (Accessed 24 January 2026)

Goldlust, R. 2023 *Housing for a Changing Climate: The Commonwealth Environmental Building Station in 1950s Australia. Environment & Society Portal, Arcadia,* Spring 2023, no. 1. Rachel Carson Center for Environment and Society. doi:10.5282/rcc/9557

Grillo, F. (2020). *'In France a prefabricated social housing is built with straw and wood'*. *Domus*, 3 April 2020. Available at: https://www.domusweb.it/en/architecture/gallery/2020/04/03/in-france-a-prefabricated-social-housing-is-built-with-straw-and-wood.html (Accessed 12 February 2026)

Habert, G., Miller, S.A., John, V.M. et al. 2020. *Environmental impacts and decarbonization strategies in the cement and concrete industries. Nat Rev Earth Environ* 1, 559–573 (2020). https://doi.org/10.1038/s43017-020-0093-3

Haff, P. K. 2014. *Technology as a geological phenomenon: implications for human well-being. Geological Society,* London, Special Publications, 395(1), 301-309. https://doi.org/10.1144/SP395.4

Hajer, M. and Oomen, J. 2025. *Captured Futures: Rethinking the Drama of Environmental Politics.* Oxford Academic Press, online edition, 28 April 2025. Available at: https://doi.org/10.1093/9780198955382.001.0001 (Accessed 11 March 2026)

Hansen, R.N., Hoxha, E., Birgisdóttir, H., Pittau, F. 2025. *Reducing the land-use impact of wooden buildings with fast-growing biobased materials: A Danish case study. Resources, Conservation and Recycling*, Volume 212, 2025, 107926, ISSN 0921-3449, https://doi.org/10.1016/j.resconrec.2024.107926.

Hariadi, K.S., & Carlisle, S. 2025. *A Literature Review on the Health Impacts of Wood and Mass Timber Buildings*. Carbon Leadership Forum, Bellevue, WA. https://hdl.handle.net/1773/53047

Hickel, J. 2021. *Less Is More*. London, England: Windmill Books

Hickel, J. and Kallis, G. 2020. *'Is Green Growth Possible?'*. *New Political Economy* 25 (4): 469–86. doi:10.1080/13563467.2019.1598964.

Hill, D. 2012. *Dark Matter and Trojan Horses: A Strategic Design Playbook*. Strelka Press, Moscow

Hill, D. 2022. *Designing Missions*. Vinnova, Sweden

Hill, D. and Mazzucato, M. 2024. *Modern Housing: An environmental common good*. Council on Urban Initiatives. (CUI DP 2024-02). UCL Institute for Innovation and Public Purpose Working Paper Series: IIPP WP 2024-03: Available at: https://www.ucl.ac.uk/bartlett/publications/2024/mar/modern-housing-environmental-common-good (Accessed 14 December 2025)

Hill, D. and Melander, A. 2025. *'Strategic Design for Public Purpose: Enriched and Expanded Practices for Human-Technology Interaction'*. In E. Malakhatka and M. Wiberg (eds.), *Human-Technology Interaction, Springer Series in Adaptive Environments*, https://doi.org/10.1007/978-3-031-78357-9_2

Hill, D. 2025. *The Real Housing Crisis. Future Observatory Journal.* Available at: https://fojournal.org/essay/the-real-housing-crisis/ (Accessed 10 January 2026)

Hirst, W. 2025. *'City of London's 'retrofit first' policy to come into force'*. *Architect's Journal*. 22 January 2025. Available at: https://www.architectsjournal.co.uk/news/city-of-londons-retrofit-first-policy-to-come-into-force (Accessed 14 January 2026)

Horup, H., Bruhn, S., Hoxha, E., Birgisdottir, H., Qvist Secher, A., Ohms, P., Hauschild, M. 2025. *Absolute sustainability assessment of the Danish building sector through prospective LCA. Science of The Total Environment*, Volume 966, 2025, 178780, ISSN 0048-9697 https://doi.org/10.1016/j.scitotenv.2025.178780.

HSE (Health and Safety Executive) 2025. *Construction statistics in Great Britain*, 2025. Available at: https://www.hse.gov.uk/statistics/assets/docs/construction.pdf (Accessed 16 January 2026)

Infrastructure Australia. 2024. 2024 Infrastructure Market Capacity Report. Available at: https://www.infrastructureaustralia.gov.au/reports/2024-infrastructure-market-capacity-report (Accessed 18 February 2026)

Jarman, D. 1991. *Modern nature: The journals of Derek Jarman*. Century

Jørgensen, M. & Lee, M. 2024. *Byggestop? / Stop Building? Magasin for Bygningskunst og Kultur.* Nr.7 2024, Royal Danish Academy. Available at: https://bygningskunstogkultur.dk/nr-7-2024/byggestop (Accessed 12 February 2026)

Kaila, A. M., & Heikkinen, P. 2020. *'Designing for Durability: Helsinki Central Library's Wood Facade'. Technology|Architecture + Design*, 4(1), 24–34. https://doi.org/10.1080/24751448.2020.1705713

Kattel, R., Mazzucato, M., Puttick, R., Chau, B., Goulden, A., Baafi, K., Hill, D., Gomez-Mont, G., Tarp, M., Maldonado Acosta, M., Kalema, N., and Fernandez-Monge, F. (2025). *Assessing Dynamic Capabilities in City Governments: Creating a Public Sector Capabilities Index*. UCL Institute for Innovation and Public Purpose. IIPP Policy Report 2025/05. ISBN: 978-1-917384-40-7

Kawashima, N. 2025. *Towards A Delightful Architecture With Nature: Nori Kawashima Works*. ISBN: 978-4-9913552-1-9

Conclusion / **References**

Kemp, R., Schot, J., & Hoogma, R. 1998. *Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. Technology Analysis & Strategic Management*, 10(2), 175–198. https://doi.org/10.1080/09537329808524310

Kennedy, K. 2024. *Cello: A Journey Through Silence to Sound*. Pegasus Books.

Kiss, B. M., Visintin, G. Garrard, E, and Bekessy, S. 2025. *Evaluating Biodiversity Criteria in Green Building Rating Schemes: Toward 'Nature Positive' Development. Sustainable Development* 33, no. 4: 4884–4895. https://doi.org/10.1002/sd.3369

Klein, E., and Thompson, D. 2025. *Abundance*. Avid Reader Press, an imprint of Simon & Schuster

Leloup, M., Weiner, C., Hussein, J., Leclercq, F., and Laigle, P. 2022. *The Wood that Makes Our Cities*. Park Books.

Li, C., Pradhan, P., Chen, G. et al. *Carbon footprint of the construction sector is projected to double by 2050 globally*. *Commun Earth Environ* 6, 831 (2025). https://doi.org/10.108/s43247-025-02840-x

Liboiron, M. 2021. *Pollution is Colonialism*. Duke University Pres

Mack, J. 2019. 'Flying people meet flying panels: a Swedish conrete paradise', in Alonso, P. I., & Palmarola, H. (eds.). 2019. *Flying Panels: How Concrete Panels Changed the World*. DOM Publishers/Ediciones UC

Malterre-Barthes, C. 2021. *The Devil Is in the Details—Who Is It That the World Belongs To?* In Space Caviar (ed.). 2021. *Non- Extractive Architecture—Designing without Depletion*. Sternberg Press, Berlin.

Malterre-Barthes, C. 2025. *A Moratorium on New Construction*. Critical Spatial Practice 14, Sternberg Press, London

Mant, A. 2019. *'Why construction is still getting the circular economy wrong'*. *Building*, 14 May 2019. Available at: https://www.building.co.uk/comment/why-construction-is-still-getting-the-circular-economy-wrong/5099456.article (Accessed 3 June 2025)

Marsh, A., Velenturf, A., Bernal, S. 2022. *Circular Economy strategies for concrete: implementation and integration. Journal of Cleaner Production*, Volume 362, 2022, 132486, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2022.132486

Martin, H., Chebrolu, D., Chadee, A., Brooks, T.. 2024. *Too good to waste: Examining circular economy opportunities, barriers, and indicators for sustainable construction and demolition waste management. Sustainable Production and Consumption*, Volume 48, 2024, Pages 460-480, ISSN 2352-5509 https://doi.org/10.1016/j.spc.2024.05.026

Martínez de Arbulo, A. 2023. *The Ship of Theseus: a misleading paradox? The authenticity of wooden built heritage in Japanese conservation practice. Journal of Architectural Conservation*, 29(2), 151–167. https://doi.org/10.1080/13556207.2022.2160554

Material Cultures. 2020. *Material Reform*. Mack Books

Material Cultures. 2023. *'Wetlands and Construction: An opportunity for Berlin-Brandenburg'*. Available at: https://materialcultures.org/2023-wetlands-and-construction-report/ (Accessed: 19 January 2026)

Material Cultures. 2025a. *Growing Place*. Available at: https://materialcultures.org/film_growing-place_2025/ (Accessed: 14 January 2026)

Material Cultures. 2025b. *'Building Skills: A Material Strategy for Birmingham and the West Midlands'*. Available at: https://materialcultures.org/2024-building-skills-report/ (Accessed: 13 January 2026)

Mazzucato, M. 2021. *Mission economy: A moonshot guide to changing capitalism*. Allen Lane/Harper Business.

Mazzucato, M. and Collington, R. 2023. *The Big Con.* Allen Lane, London.

Mazzucato, M. 2024. *'Governing the Economics of the Common Good: From Correcting Market Failures to Shaping Collective Goals'. Journal of Economic Policy Reform* 27 (1): 1–24. doi:10.1080/17487870.2023.2280969.

McGilchrist, I. 2019. *The master and his emissary: The divided brain and the making of the Western world: New expanded edition* (2nd ed.). Yale University Press.

McGilchrist, I. 2021. *The Matter With Things. Our Brains, Our Delusions, and the Unmaking of the World*. Perspectiva Press.

McNeill, J. R., & Engelke, P. 2016. *The great acceleration: An environmental history of the Anthropocene since 1945*. Harvard University Press.

Meadows, D. 2008. *Thinking in Systems: A Primer*. Edited by Diana Wright. White River Junction, VT: Chelsea Green Publishing.

Meredith, M. 2025. *Smaller Architecture*. Architecture Exchange.

Metsä. 2026. *'Xylino: A New Benchmark for Modular Timber Construction'*. Available at: https://www.metsagroup.com/metsawood/news-and-publications/articles/xylino/ (Accessed 26 February 2026)

Miller-Yeaman, R. 2022. *'Producing the House: The Commonwealth Experimental Building Station and Housing Research'*. In *Proceedings of the Society of Architectural Historians, Australia and New Zealand*. Adelaide, Australia: SAHANZ. https://doi.org/10.55939/a3995ptgqb

Misselwitz, P. and Organschi, A. 2024. *Toward Re-Entanglement: A Charter for the City and the Earth*. Bauhaus Earth Essays 1.

Moon, W. 2017. *Cedric Price: Radical Pragmatist, in Pursuit of Lightness. Journal of Architectural Education,* 71(2), 171–183. https://doi.org/10.1080/10464883.2017.1340772

Mossin, N., Beim, A., and Hau, I. 2023. *Innovation of Nothing: The Capabilities Needed To Lead Sustainable Change in the Built Environment*. Royal Danish Academy.

Munch-Petersen, P. and Beim, A. 2023. *'Absolute Sustainability'*, in Mossin, N., Beim, A., and Hau, I. 2023. *Innovation of Nothing: The Capabilities Needed To Lead Sustainable Change in the Built Environment*. Royal Danish Academy.

Napiontek et al., J, *'Live (a) Little: GHG Emissions from Residential Building Materials for all 400 Counties and Cities of Germany until 2050', Resources, Conservation and Recycling* 215, no. 108117 (April 2025)

Naseem, S. and Rizwan, M. 2025. *Sustainable construction and combo nanocellulose: A synergistic approach to greener building materials. Energy and Buildings*, Volume 328, 2025, 115218, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2024.115218.

Nousaku, F. and Tsuneyama, M. 2024. *Urban Wild Ecology*. TOTO Publishing, Tokyo.

Obrist, H. (ed). 2003. *Re: CP*. Birkhäuser, Basel

OFFICE. 2021. *Retain, Repair, Reinvest: Ascot Vale Estate Feasibility Study and Alternative Design Proposal*. Available at: https://office.org.au/project/retain-repair-reinvest/ (Accessed 15 January 2026)

Oikos. 2025. *Paille et Réhabilitation de logements collectifs*. Available at: https://oikos-ecoconstruction.com/paille-et-rehabilitation-de-logements-collectifs/ (Accessed 12 February 2026)

Ormond. J., Goodman M.K. 2015. *A new regime of carbon counting: The practices and politics of accounting for everyday carbon through CO2e, Global Environmental Change*, Volume 34, 2015 Pages 119-131, ISSN 0959-3780, https://doi.org/10.1016/j.gloenvcha.2015.04.011

Peters, G. B. 2021. *Administrative Traditions: Understanding the Roots of Contemporary Administrative Behavior*. Oxford University Press

Petersen, T.L. 2024. *'Finite Earth, Open-Ended Architecture? Framing a Qualitative Ecological Perspective on Housing'*. Conference paper written for the EAAE/ARCC Conference *Architecture into the Unknown*, Aarhus, 2024.

Petersen, T.L. 2025. *Practicing Architecture with Care: An Investigation into Architectural Strategies and Environmental Perspectives Beyond Metrics* [Unpublished PhD Thesis]. Royal Danish Academy. Available at: https://adk.elsevierpure.com/da/publications/practicing-architecture-with-care-an-investigation-into-architect/

Pihlmann, S. and Dickinson, A. 2025. *Making Matter What Too Often Does Not Matter: Material Protagonists of a Site-Derived Architecture*. Verlag der Buchhandlung Walther un Franz König, Köln

Planetary Boundaries Science (PBScience). 2025. *Planetary Health Check 2025*. Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany

Plumwood, V. 2008. *Shadow Places and the Politics of Dwelling. Ecological Humanities*, Issue 44, March 2008

Potting, J. Hekkert, M. Worrell, E. and Hanemaaijer, A. 2016. Circular Economy: Measuring innovation in product chains. PBL Netherlands Environmental Assessment Agency, The Hague.

Premakumara, A. and Siriwardana, C. 2025. *A Comprehensive Approach for Assessing the Causes of Low Productivity in the Construction Sector: A Systematic Categorization and Ranking Using Pareto and Fuzzy Analysis. Construction Management and Economics* 43 (1): 40–58. doi:10.1080/01446193.2024.2377712.

Reduction Roadmap. 2024. *Beyond the Roadmap: A transition plan for the Danish building industry*. Version 2. 14. November, 2024. www.reductionroadmap.dk

Regional Urban Planning Regulation (RUPR). *Adopted in the Second Reading*, Brussels Regional Public Service Urbanism and Heritage, 18 April 2024. Updated in 2024 and waiting to be approved by the incoming government. Available at: https://urban.brussels/en/articles/the-regional-urban-planning-regulation-rupr-adopted-in-the-second-reading

Reike, D., Vermeulen, W.J., & Witjes, S. 2017. '*The circular economy: New or Refurbished as CE 3.0?—Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options'. Resources, Conservation & Recycling* 135 (2018) 246–264

Rockström, J., Steffen, W., Noone, K. et al. 2009. *A safe operating space for humanity*. *Nature* 461, 472–475 (2009). https://doi.org/10.1038/461472a

Rogers E. 2003. *Diffusion of Innovations*, 5th Edition: Free Press

Rose, S. 2021. *''Our biggest challenge? Lack of imagination': the scientists turning the desert green'. The Guardian*, 20 March 2021. Available at: https://www.theguardian.com/environment/2021/mar/20/our-biggest-challenge-lack-of-imagination-the-scientists-turning-the-desert-green (Accessed 15 August 2025)

Ross, J. 2026. '90% of Australians Demand 'Country of Origin' Labels on Timber', *WoodCentral*, 13 February 2026. Available at: https://woodcentral.com.au/90-of-australians-demand-country-of-origin-labels-on-timber/ (Accessed 19 February 2026)

Rougelot, B. 2024. *'Construction site-school rue des Couronnes', Construction21 France*. Available at: https://www.construction21.org/france/case-studies/h/chantier-ecole-rue-des-couronnes.html (Accessed 12 February 2026)

Rousseau, J. F., Lauzon, A., & Marschke, M. 2025. *Can green concrete help address the sand and aggregate crisis? A scoping literature review. Journal of Environmental Planning and Management*, 68(8), 1788–1806. https://doi.org/10.1080/09640568.2024.2303630

Savini, F. 2025. *The circular economy is over: The scalar politics of circular production. Urban Studies*, 0(0). https://doi.org/10.1177/00420980251383341

Saito, K. 2024. *Slow Down: The Degrowth Manifesto*. Translated by Brian Bergstrom. New York: Astra House

Schmidt, M., Crawford, R. H., & Warren-Myers, G. 2020. *Quantifying Australia's lifecycle greenhouse gas emissions for new homes. Energy and Buildings*, 224, 110287.

Shinohara, Yuma, and Andreas Ruby, eds. 2022. Make Do With Now: New Directions in Japanese Architecture, Christoph Merian Verlag

Space Caviar, editor. *Non-Extractive Architecture: On Designing without Depletion, Vol. 1*. Sternberg Press/V-A-C Press, 2021

Stangl, J., Borsos, A. & Thurner, S. 2026. *Using firm-level supply chain networks to measure the speed of the energy transition. Nature Communications* (2026). https://doi.org/10.1038/s41467-026-69358-4

Stora Enso. 2025. '*The World's First Mass Timber Data Centre'.* storaenso.com, published 4 November 2025. Available at: https://www.storaenso.com/en/newsroom/news/2025/11/the-worlds-first-mass-timber-data-centre (Accessed 16 January 2026)

Studio Suddo Neuve. 2025. *Back to Earth: Urbanization without Depletion. Bauhaus Earth Manual 1*. Jovis Verlag, Walter de Gruyter GmbH, Berlin/Boston

Sustainable Chemistry Research Unit. 2026. *'Forest-based resins challenge fossil materials in wind turbines, boats and high-performance adhesives'*. Published at University of Oulu. Available at: https://www.oulu.fi/en/news/forest-based-resins-challenge-fossil-materials-wind-turbines-boats-and-high-performance-adhesives (Accessed: 26 February 2026)

Tange, K, & Kawazoe, N. 1965. *Ise: Prototype of Japanese Architecture* (Y. Watanabe, Photo.; E. Klestadt & J. Bester, Trans.). MIT Press.

Terho, R., Dal Pont, B., Kainulainen, T., Aliotta, L., Gigante, V., Lazzeri, A., Heiskanen, J.. 2026. *Circular composite materials: Biomass-based furan epoxies with high-performance and closed-loop recyclability. Composites Part B: Engineering*, Volume 311, 2026, 113256, ISSN 1359-8368, https://doi.org/10.1016/j.compositesb.2025.113256

Thie, E. 2021. *'Road to decarbonisation: timber paves way for more sustainable road bridges'*. Arup.com, published August 2021. Available at: https://www.arup.com/insights/road-to-decarbonisation-timber-paves-way-for-more-sustainable-road-bridges/ (Accessed 16 January 2026)

Tronto, J. C. 2015. *Who cares? How to reshape a democratic politics*. Cornell University Press.

Tufte, E. 1990. *Envisioning Information*. Graphics Press

United Nations Environment Program (UNEP). 2023. Building Materials and the Climate: Constructing a New Future. UNEP, Nairobi, Kenya

Van Gerrewey, C. 2025. *Recycling Brussels. Future Observatory Journal No. 3*. Available at: https://fojournal.org/case-study/recycling-brussels/ (Accessed 29 December 2025)

Van Gerrewey, C. 2025. *Something completely different: Architecture in Belgium*. MIT Press.

Visibuilt. 2025. *'Danish startup creates the world's first cultivated outdoor paver – a natural alternative to cement'*. Visibuilt.com, published on 9 October 2025. Available at: https://www.visibuilt.com/danish-startup-creates-the-worlds-first-cultivated-outdoor-paver-a-natural-alternative-to-cement/ (Accessed: 16 January 2026)

Vogel J, Hickel J. Is green growth happening? An empirical analysis of achieved versus Paris-compliant CO2-GDP decoupling in high-income countries. *Lancet Planet Health*. 2023 Sep;7(9):e759-e769. doi: 10.1016/S2542-5196(23)00174-2. PMID: 37673546.

Waugh Thistleton Architects (WTA). 2024. The Black & White Building Life Cycle Assessment Report. Version 1.4, March 2024. Available at: https://waughthistleton.com/black-white-building-life-cycle-assessment/

Webb, S. 2021. *'Why the time is ripe for a return to stone as a structural material', RIBA Journal*, published 29 May 2020. Available at: https://www.ribaj.com/intelligence/stone-as-a-structural-material-embodied-carbon-sustainability/ (Accessed: 29 November 2025)

Westminster Council. 2026. *'Westminster Council launches Retrofit First policy and boosts affordable housing in City Plan Partial Review'*. Available at: https://www.westminster.gov.uk/news/westminster-council-launches-retrofit-first-policy-and-boosts-affordable-housing-city-plan-partial (Accessed 14 January 2026)

Whittle, L. 2020. *Analysis of Effects of bushfires and COVID-19 on the forestry and wood processing sectors*. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. https://doi.org/10.25814/5ef02ef4a3a96

Whyte, S, K Skillington, C Candido, Y Zhang, D Fatourehchi, S Finlay, HF Chan, et al. 2025. *'Understanding the Effects of Timber Rich Workplaces on Occupants Perceived Productivity and Health: A Pilot Study'. Scientific Reports* 15 (1). https://doi.org/10.1038/s41598-025-22934-y.

Wines, S. 2026. *Financing a Thriving Bioeconomy: A Challenge-Led, Complexity-Informed Approach*. published at CoLabs website, 12 January 2026. Available at: https://colabs.com.au/community/financing-a-thriving-bioeconomy-a-challenge-led-complexity-informed-approach

World Economic Forum (WEF). 2026. *Global Risks Report 2026*. January 14 2026. Available at: https://www.weforum.org/publications/global-risks-report-2026/digest/ (Accessed 12 March 2026)

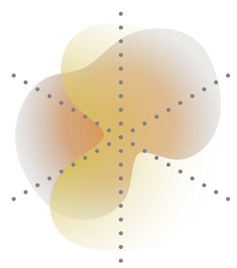
Wolpert M., and Rutter, H. 2018. *Using flawed, uncertain, proximate and sparse (FUPS) data in the context of complexity: learning from the case of child mental health. BMC Med*. 2018 Jun 13;16(1):82. doi: 10.1186/s12916-018-1079-6

World Wildlife Fund (WWF). 2024. *Living Planet Report 2024—A System in Peril*. WWF, Gland, Switzerland

zu Ermgassen, S. O. S. E., Drewniok, M. P., Bull, J. W., Corlet Walker, C. M., Mancini, M., Ryan-Collins, J., & Cabrera Serrenho, A. 2022. *A home for all within planetary boundaries: Pathways for meeting England's housing needs without transgressing national climate and biodiversity goals. Ecological Economics*, 201, 107562

Bushey Cemetery, London Waugh Thistleton Architects (2017)
Prayer halls are constructed from solid rammed earth walls, lined with English Oak and connected by a cloistered timber colonnade. Sections of the rammed earth are left exposed in the ceremonial spaces.

Data sources



The material scores presented in Circle are derived through a comparative evaluation of available resources. Drawing from critiques of 'numerical environmentalism' as noted throughout, the aim is not to produce exact, universalising calculations for what are complex, ambiguous and highly contextual systems, but to enable consistent comparison across materials using a high-level common scale.

This approach allows meaningful inferences to be made about material choices, but it also foregrounds the need to engage further. Readings for materials and material assemblages draw together published life-cycle literature, environmental product declarations, industry reporting, and architectural research. **Embodied emissions** values were informed by global and Australian datasets, including the *EPiC Database* and international assessments of material-related emissions in the built environment. These sources typically provide ranges rather than precise figures; Circle translates those ranges into relative score bands so materials can be positioned consistently within the scoring system.

Circularity and end-of-life scores are informed by documented reuse pathways, recyclability, biodegradability, and known downcycling. **Ecological impact** draws on the planetary boundaries framework developed by an international group of Earth system scientists. **Durability** scores reflect expected service life and structural reliability under typical building conditions, noting that longevity can support circular outcomes only when materials are recoverable and reusable at end of life.

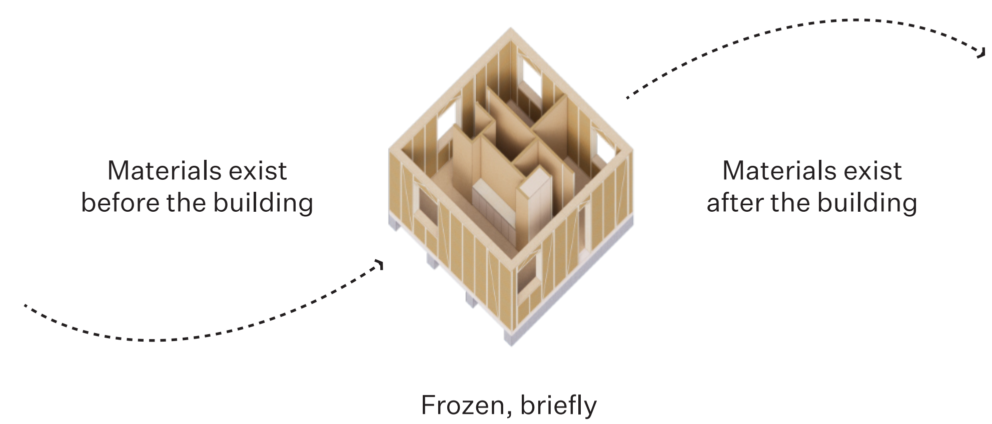
Overall, scores are comparative, not absolute. Each category is derived by synthesising multiple sources into a relative position on a common scale, and can be refined as better data becomes available.

— EPiC Database. 2024. *Environmental Performance in Construction Database 2024*. Melbourne: University of Melbourne.
— United Nations Environment Programme. 2023. *Building Materials and the Climate: Constructing a New Future*. Nairobi: UNEP.
— Australian Government. 2023. *Australia's Carbon Budget and Emissions Pathways*. Canberra.
— United Nations Environment Programme. 2023. *Global Status Report for Buildings and Construction*. Nairobi: UNEP.
— Lewis, Paul, Marc Tsurumaki, and David J. Lewis. 2022. *Manual of Biogenic House Sections*. New York: Princeton Architectural Press.
— International Energy Agency. 2023. *Emissions Gap Report 2023*. Paris: IEA.
— Realdania and JAJA Architects. 2025. *Veje til Biobaseret Byggeri: Et blik på tværs [Paths to Bio-based Construction: A Cross-cutting View]*. January 2025.
— United Nations Environment Programme. 2023. *Emissions Gap Report 2023: Broken Record - Temperatures Hit New Highs, Yet World Fails to Cut Emissions (Again)*. Nairobi: UNEP.
— BC Materials. 2023. *Léém: General Guide – Building Sustainably with Earth*. Brussels.
— EcoCocon. *Technical Specifications. Version 10/2023*. EcoCocon, 2023.
— Webb, Steve. *'Stone Age: A New Architecture from an Old Material.' The Architectural Review*, April 6, 2022.
— WeCanMake, BlokBuild, and Pryce & Myers. 2024. *Homegrown Homes for People & Planet: A Mass Local Approach to Building Timber Homes in Every Neighbourhood*. Available at: https://wecanmake.org/wp-content/uploads/2024/07/HGH-final-report-Online-version.pdf (Accessed 25 January 2026)

Events

During its development between May and December 2025, *Circle Phase 1* was presented and discussed at the following events:

— A New Normal for Melbourne Design Week (18–05–25)
— Australian Institute of Architects Victoria Circular Economy Symposium (Melbourne, 05–06–25)
— WeCanMake launch, with Waugh Thistleton and Dark Matter Labs (Bristol, UK, 15–05–25)
— Swedish Australian Sustainable Innovation Technology and Design Summit (Melbourne, 18–09–25)
— Panel on Urban Liveability, Centre for Liveable Cities, Singapore Government (Singapore, 02–09–25)
— Singapore Science week on Regenerative Design (National University of Singapore (Singapore, 03–09–25)
— Circular Economy for Climate and Environment conference, University of Melbourne (Melbourne, 23–09–25)
— World Design Cities Conference (Shanghai, 25–09–25)
— Emerging Practices Conference, Tongji University (Shanghai, 26–09–25)
— Boyd Foundation event 'Living in Australia' (Melbourne, 10–10–25)
— Monash Sustainable Development Institute (Melbourne, 23–10–26)
— Circle was discussed, alongside Reduction Roadmap, on the podcasts *Climate360°* and *Flourish*.



Credits

Image credits

P.6-7 Photo of Hyllie building under construction by Dan Hill
P.30-31 Photo of Woodleigh School building by Dan Hill
P.32-33 Photo of hemp harvesting by Mark Stebnicki
P.39 Photo of hemp harvesting by Mark Stebnicki
P.40-41 Photo of Powerhouse Place by Tom Ross, courtesy of Public Realm Lab
P.42-43 Photo of straw from iStockPhoto
P.48-49 Photo of Sundby School under construction by Rasmus Hjortshøj, courtesy of Henning Larsen
P.50-51 Photo of Hyllie building under construction by Dan Hill
P.52-53 Photo of The Plus building under construction courtesy of Vestre AS
P.59 Photo of Helsinki Central Library building by Dan Hill
P.60-61 Photo of stone from iStockPhoto
P.66-67 Photo of stone bricks in Stone Demonstrator by Bas Princen, courtesy of Future Observatory
P.68-69 Photo of Heide Modern building by Dan Hill
P.70-71 Photo of earth from iStockPhoto
P.77 Photo of Quatre Cheminée by Salem Mostefaoui, courtesy of Déchelette Architecture
P.78-79 Photo of Ginza Sony Park building by Dan Hill
P.80-81 Photo of concrete from iStockPhoto
P.86-87 Photo of concrete production from iStockPhoto
P.88-89 Photo of steel from iStockPhoto
P.94-95 Photo of steel from iStockPhoto
P.96-97 Photo of glass from iStockPhoto
P.102-103 Photo of glass from iStockPhoto
P.104-105 Photo of brick from iStockPhoto
P.110-111 Photo of plasterboard from iStockPhoto
P.119 Photo of Hyllie building under construction by Dan Hill
P.120-121 Photo of Stone Demonstrator by Bas Princen, courtesy of Future Observatory
P.123 Photo of Stone Demonstrator by Bas Princen, courtesy of Future Observatory
P.125 Photo of Garden with Housing under construction by Max Hart Nibbrig, courtesy of Studio Nauta
P.127 Photo of Hyllie building under construction by Dan Hill
P.129 Photo of Feldballe School under construction, courtesy of Henning Larsen
P.135 Photo of Thoravej 29 under reconstruction by Hampus Berndtson, courtesy of Pihlmann Architects
P.139 Photo of concrete from iStockPhoto
P.141 Photo of Stone Demonstrator by Bas Princen, courtesy of Future Observatory
P.147 Photo of Local Resource/Collective Knowledge installation by Rasmus Hjortshøj, courtesy of GXN
P.151 Photo of Home Truth installation courtesy of Breathe
P.153 Photo of Black & White Building by Ed Reeve courtesy of Waugh Thistleton Architects
P.157 Photo of Master Builders Victoria under construction by Tom Ross, courtesy of Fieldwork
P.161 Photo of Wilya Janta Explain House 1 by Andrew Quilty
P.168-169 Photo of Black & White Building under construction by Daniel Tucker, courtesy of Waugh Thistleton Architects
P.174-175 Photo of building façade system prototype made from wastewater sludge, courtesy of Tim Schork
P.180-181 Photo of Master Builders Victoria during renovation by Tom Ross, courtesy of Fieldwork
P.188-189 Photo of Bushey Cemetery under construction by Lewis Khan, courtesy of Waugh Thistleton Architects

Production credits

Original research and documentation by Dan Hill, André Bonnice, and Chris Jensen. Graphic design by Dan Hill and André Bonnice. Drawings of prototypes on pages 130-145 by André Bonnice. Typefaces are *Untitled Sans* and *Martina Plantijn* by Klim Type Foundry. A physical version of this report was printed on recycled paper by Newspaper Club—some copies are available on request.

Australian Government
Department of Industry, Science and Resources
Cooperative Research Centres Program