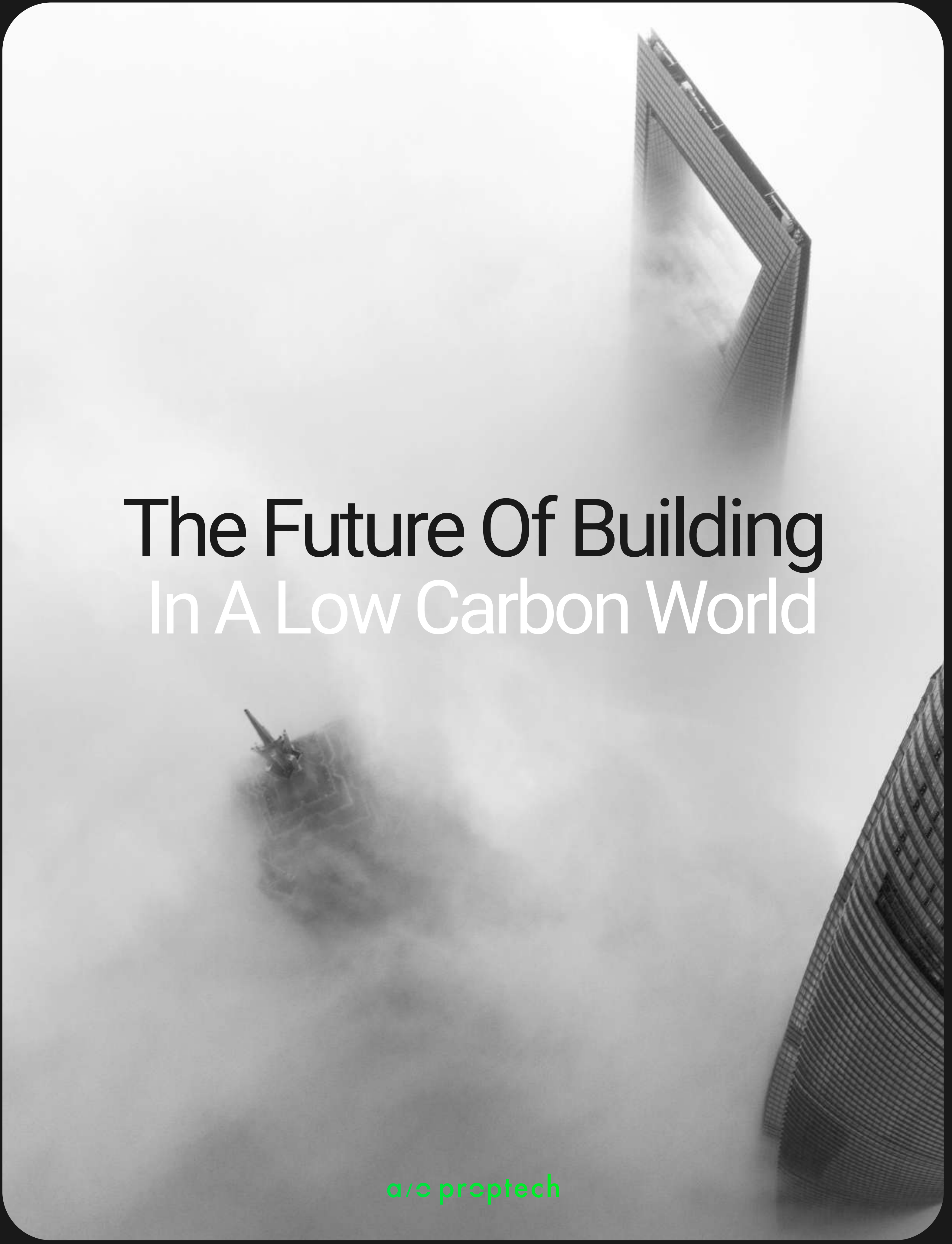


The Future Of Building In A Low Carbon World

a/o proptech

Contents

Foreword

In order to meet the requirements of the COP21 Paris agreement, the building sector must accelerate its transition to net zero. Alongside retrofitting, the decarbonisation of new construction will play a critical role. As much as 8% of global GHG emissions come from concrete alone, with a third of solid waste in Europe and North America coming from the construction and demolition of our buildings. The numbers are staggering.

New buildings must improve energy efficiency, reduce embodied carbon emissions and material waste, and facilitate the broader energy transition by enabling us to harvest, store and distribute renewable energy locally in a decentralised fashion within our built world. Upcoming regulations will enforce the adoption at large of new standards when it comes to wastage and embodied carbon. Developing the next generation of buildings with nature includes leveraging mass timber and other plant-based materials as carbon storage devices, or using negative carbon cement. These are just a few of the many exciting breakthrough innovations the sector must embrace to accelerate its transition forward.

In this report, we map out the many different angles and aspects surrounding innovation in construction to help the sector transition more rapidly into a more efficient and climate friendly industry. Decarbonising construction is extra challenging because of the role played by its supply chain, the geolocation of raw materials, and complex permitting regulations. Each stage of building design and construction has a significant impact on the overall efficiency and carbon footprint of the sector.

Industrialising the building decarbonisation process is multi-faceted and requires the combination of different technologies, accurate measurement tools, emerging skillsets, and the integration of newly formed supply chains. Tackling the decarbonisation challenge effectively requires the implementation of clear, pragmatic and consistent global regulations that extend beyond the headline commitments made by political leaders.

There has never been a greater sense of urgency within the industry to transition forward. The built world accounts for 40% of global GHG emissions and within this, embodied carbon represents a third of the sector's impact. The acceleration and deployment of green construction technology, combined with regulatory induced adoption at scale, will play a key role in achieving a low carbon, energy efficient and greener economy for the next generation. The journey starts here.

Onwards and upwards.

Gregory Dewerpe
Founder

Othmane Zrikem
CDO

Executive Summary

When it comes to lifecycle emissions, the greenest building is the one that already exists. But rapid urbanisation and a rising population mean that repurposing existing stock isn't enough - we need to build much more and faster. Even if accounting for rising retrofit rates, by 2050, the global real estate footprint is expected to increase by at least fifty times the area of London. The use of optimised design, green materials, prefabrication, and circular economy practices represent four major levers to reduce embodied carbon emissions. Cities could even become carbon sinks, storing up to four-fifths of the carbon stored in the Amazon rainforest.

In our research, the first section outlines policy drivers in North American and European markets alongside the carbon storage potential of green building materials. The second section then measures investment activity in four core areas – design, materials, procurement and prefabrication. The third section deep dives into emerging trends for each subsegment. The final section assesses the regional distribution – where in the world the money is going.

It is clear that if we are to meet policy targets, green construction needs to be transformed from a bespoke use case to a mass market solution. To date, hardware solutions across prefabrication and materials have dominated green construction technology investment, yet more needs to be done to fund enabling software. Architectural automation and procurement will play a pivotal role in accelerating carbon-negative development by empowering consultants to swap out polluting building materials for green alternatives. In outlining the sector, our research identifies where the opportunities currently lie and highlights the most innovative companies working in the area.

At A/O, we have already made several investments in startups addressing these challenge areas and will continue to make many more. Our investments in 011h, Vizcab and Saqara not only support architects, developers, and investors in designing and constructing carbon-negative buildings but inform the underwriting, pricing and regulatory initiatives of a broader ecosystem of stakeholders, including regulators, municipalities, insurers and lenders.

This report forms part of an ongoing A/O series covering emerging built world technologies. In this report, we explore how automation in design, procurement and prefabrication workflows will accelerate the use of green building materials, outline the growing transition risk for real estate stakeholders brought about by embodied carbon policy frameworks and detail early stage investment activity.

Real Estate's Next Climate Frontier

Emissions in the built world are embedded across the building lifecycle, from design through to eventual deconstruction. While 'the greenest building is the one that already exists', population growth and urbanisation will see the global real estate footprint increase by 76 to 230 billion sqm by 2050 – somewhere between 50x and 150x the area of Greater London. A growing regulatory framework for embodied carbon will require green building practices to be transformed from a niche, bespoke application to a mass market construction practice.

Embodied Carbon
The Next Big Climate Challenge For Real Estate

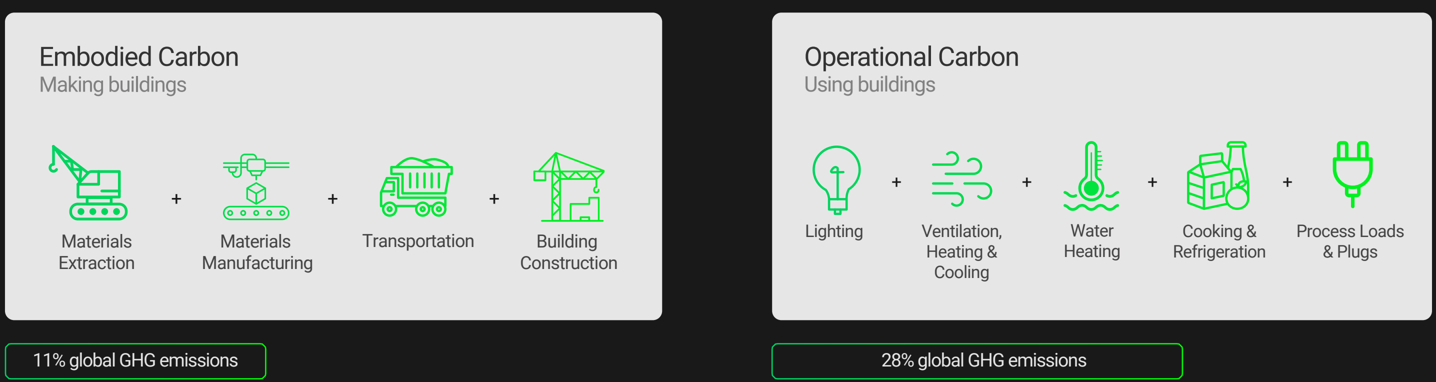


Figure 1: Unlike operational emissions, embodied carbon is fixed at the time of construction and can't be reduced thereafter.

By 2035 Embodied Carbon Will Account For
50% of Built World Emissions

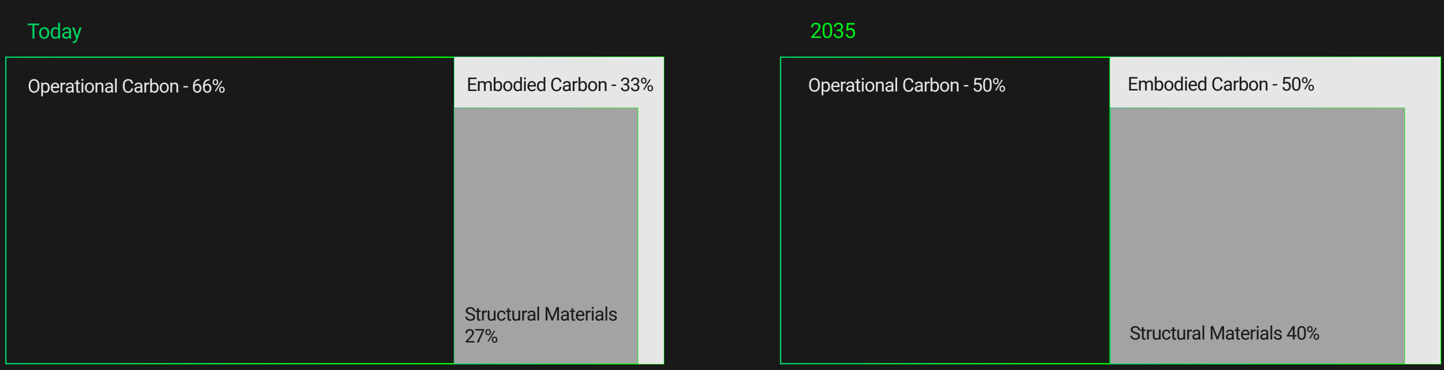
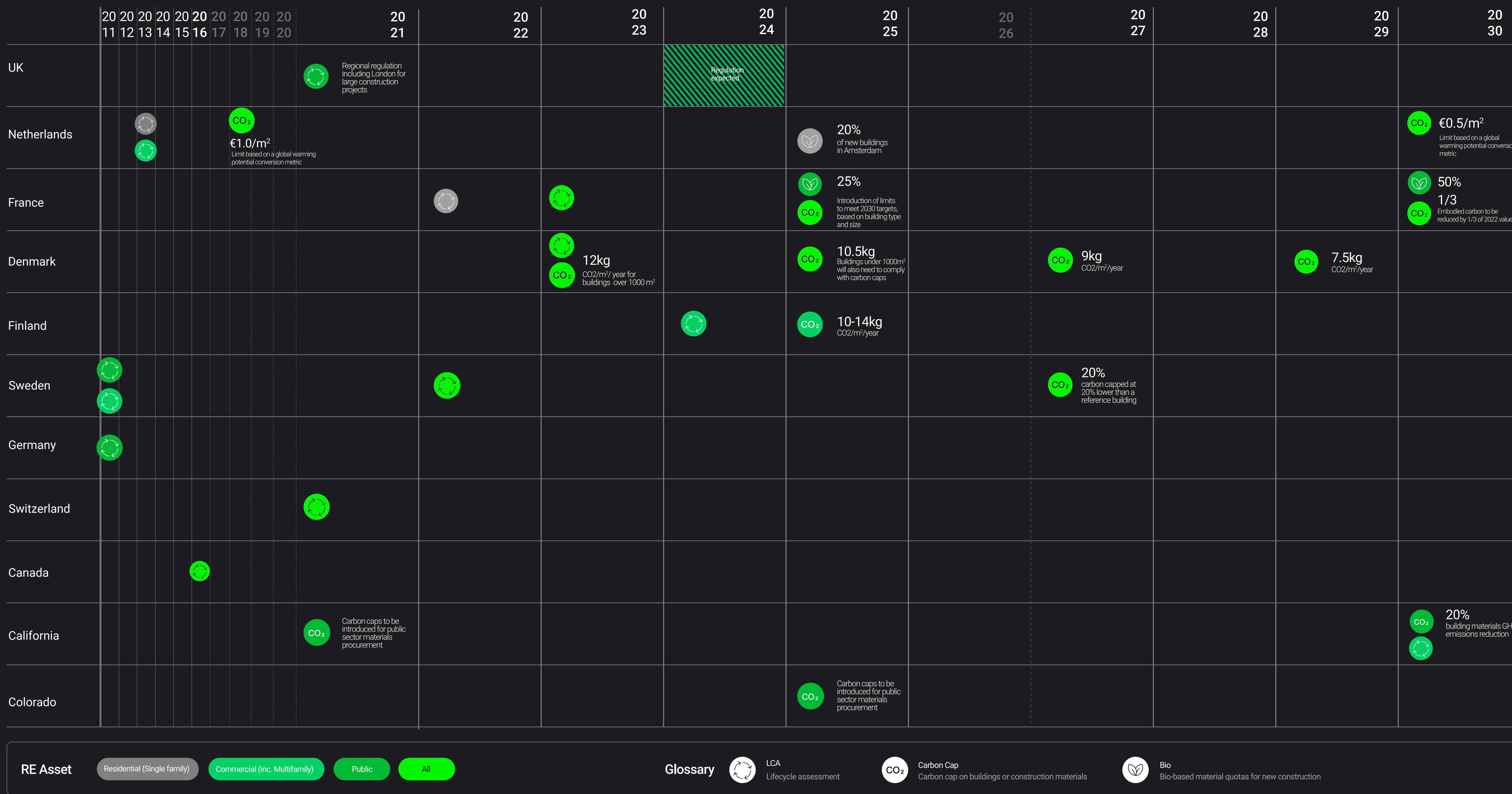
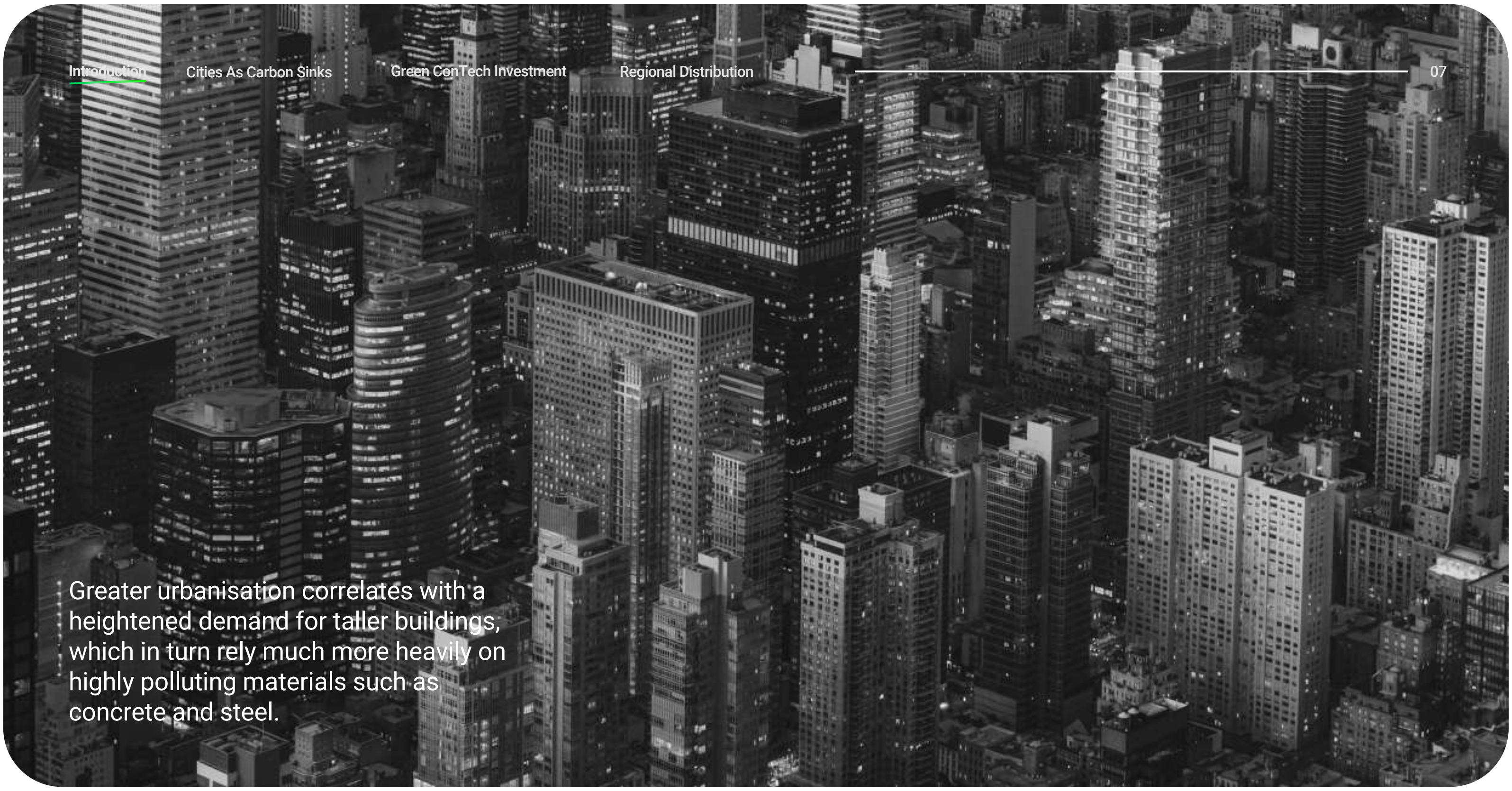


Figure 2: Tightening operational emissions caps will place a spotlight on embodied carbon.

The Race To Reduce Lifecycle Emissions By 2030

Figure 3: Embodied carbon regulation is accelerating in a number of markets across Europe and North America.





Greater urbanisation correlates with a heightened demand for taller buildings, which in turn rely much more heavily on highly polluting materials such as concrete and steel.

Figure 4: Even assuming 3% per annum retrofit rates in developed economies including Europe and North America, global construction demand will add at least another 76bn square metres in building footprint by 2050 [2]. Other estimates anticipate a 230bn square metre increase by 2060 [3].

Futureproofing Portfolios Against Transition Risk

In the race to net zero, global population growth and urbanisation will see new development concentrated in cities, with the US urbanisation rate expected to reach 97% by 2100 [4]. Greater urbanisation correlates with a heightened demand for taller buildings.

In turn, this will sustain the reliance on highly polluting materials such as concrete and steel. In the absence of scalable green building methodologies and circular economy principles, the projected global increase in real estate footprint could drive a 350% increase in construction and demolition waste [4].

While retrofitting and repurposing existing assets can save up to 95% of embodied carbon emissions relative to buying new [5], the increase in construction demand demonstrates that retrofitting will form only part of the real estate net zero equation.

It is for this reason that policymakers are turning their focus towards the regulation of embodied carbon in buildings. This marks a significant change. Until recently, embodied carbon has remained largely within the realm of voluntary certification schemes such as LEED and GRESB, with policy focused exclusively on the regulation of operational emissions. Figure 3 illustrates the acceleration in embodied carbon regulation across a number of markets. Notably, there are three key observations:

Different Regions Employ Vastly Different Policy Approaches

In the European market, regulations target a range of asset classes with a clear focus on optimising a building's whole life carbon. National frameworks often begin by consolidating environmental product declaration (EPDs) databases and requiring new developments to provide a lifecycle assessment (LCA). Next, square metre carbon caps are introduced, which tighten incrementally over time.

Policies in the US market are comparatively nascent, with the regulation focused mostly on the public sector. State level regulations seek to improve incentives for public sector procurement by implementing carbon caps for the most polluting building materials. This is met with growing efforts to foster a green building materials market, through rebates and municipal grants awarded for the development of net zero building codes.

Evolving Policy Makes It Harder To Keep Up

While some markets propose to regulate all buildings, others are more nuanced, choosing to focus on specific attributes such as end-use, type of ownership, or size. It is not uncommon to see different regulations between commercial and residential buildings, and even within the latter, different requirements for institutional and individually owned homes.

Strong Enforcement Mechanisms Rule Out Inaction

Embodied carbon regulation is more targeted than operational emission caps, applying to only certain building types and sizes. However, there are fewer loopholes and penalties can be much more severe. While operational emission caps threaten financial penalties for noncompliance, building proposals that do not comply with embodied carbon regulation could breach building regulations or fail to receive permit approval.

Unlike operational emissions, embodied carbon impact is fixed at the time of construction, meaning that once the mistake is made, it can't be undone. The current acceleration in embodied carbon regulations will intensify transition risk and add further urgency to real estate's 'carbon bubble' [6]. Figure [5] highlights the significant variation in real estate value at risk (VAR) under different climate policy scenarios [7]. There are clear benefits to futureproofing developments against any additional transition costs that could arise in the next 5-10 years as embodied carbon policy catches up with operational emissions targets.

$6.5bn

US Inflation Reduction Act funding for low carbon material investments and net zero building code development

Climate Risk = Physical Risk + Transition Risk

Physical risk: Wildfires, Storms, Heatwaves, Floods

Transition risk: Retrofit capital expenditures, Carbon taxes

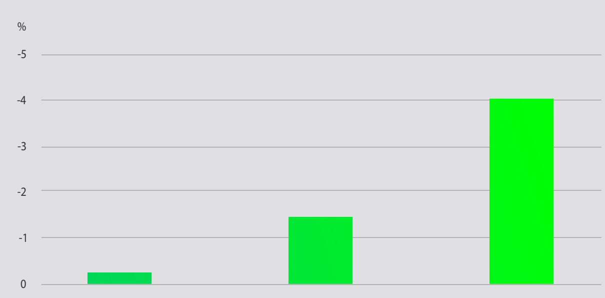
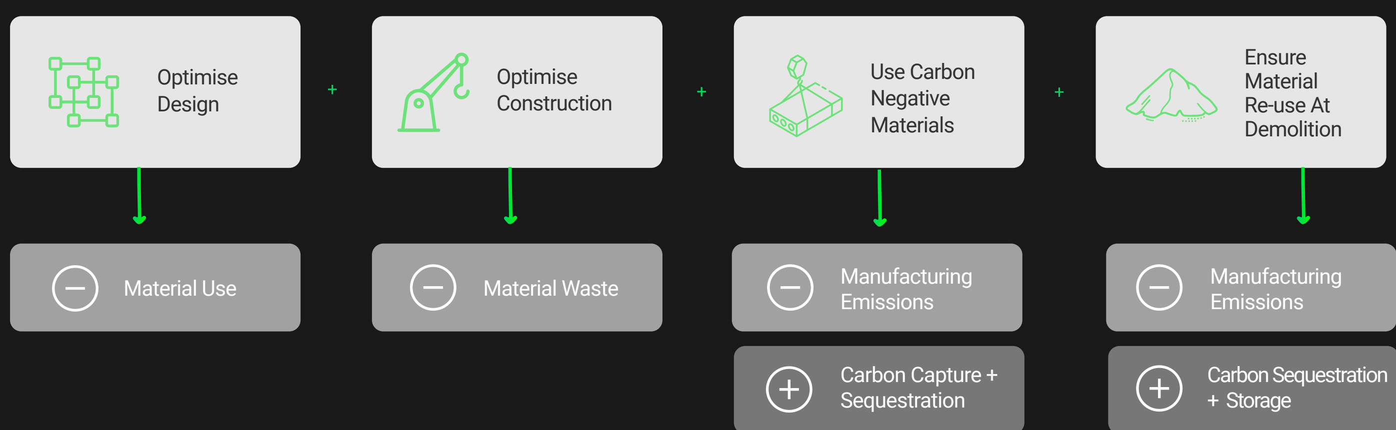


Figure 5: Variation in value at risk (VAR) due to transition risk under different climate policy scenarios [7].

Cities As Carbon Sinks

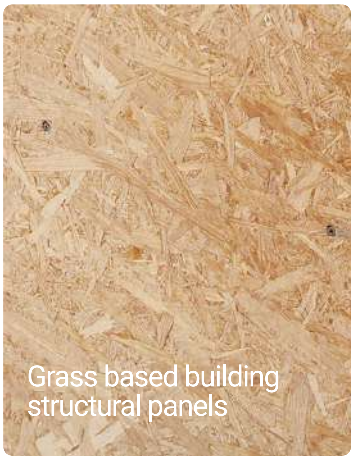
There are two primary pathways to reducing lifecycle emissions in new buildings: minimising material volumes through optimised design and construction processes, and swapping traditional materials for low carbon, bio-based or recycled alternatives. Beyond reducing lifecycle emissions, the combined use of green material and circular economy concepts can serve as a carbon removal mechanism, transforming buildings and cities into carbon sinks. Up to 60 gigatonnes of CO_2 could be stored in buildings by 2050, equivalent to four fifths of the carbon stored in the Amazon rainforest [7]. Scaling green materials and build methodologies requires navigating a highly fragmented and risk averse architectural, engineering and construction (AEC) industry, with significant data siloes creating a reliance on a small pool of specialised (and scarce) green construction skillsets.

Scaling Green Construction Principles In The Mass Market



Commercial buildings today are predominantly constructed from steel and concrete, which each contribute 8% of global GHG emissions [9]. Given the projected increase in both global construction demand and living standards across growing urban centres, the cumulative global emissions from material manufacturing could reach as much as 19 gigatonnes of CO_2 by 2050.

In other words, new buildings could represent as much as 20% of the remaining carbon budget for 2020–2050 [10]. Addressing the embodied carbon of developments requires optimised design and construction practices to reduce material volumes and wastage [11]. With cement and steel alone accounting for half of the EU's construction material emissions in 2020, it will also be critical to use low carbon alternatives to cement and steel.



A Whole Ecosystem of Green Materials
Will Be Required

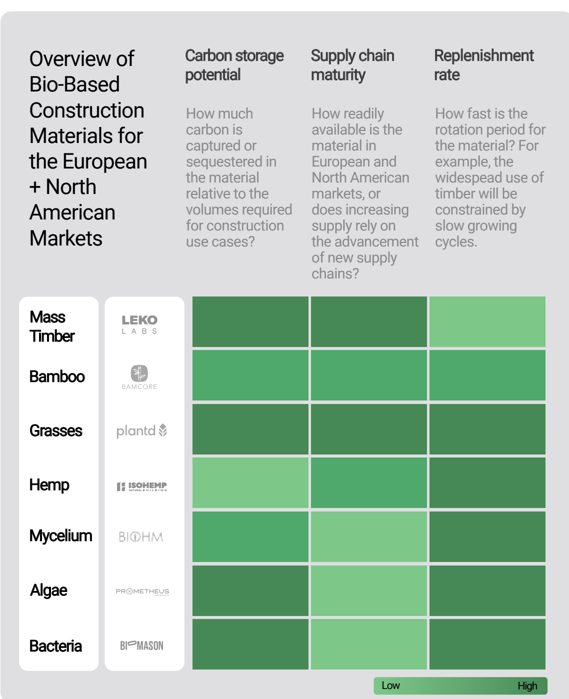
71%

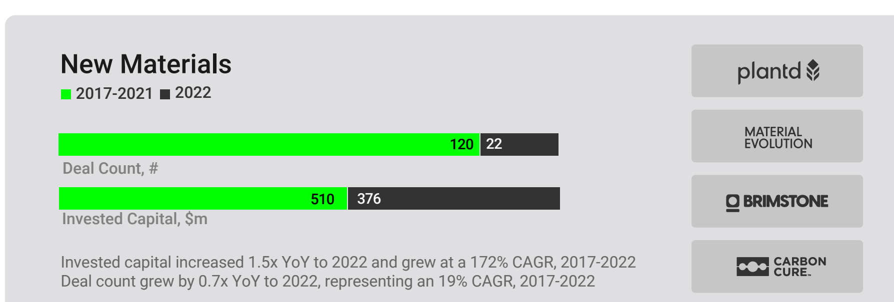
$267m of the $376m invested in green construction materials in 2022 has been allocated to low carbon cement solutions.

As much as 60% of cement emissions are caused by chemical reactions during the manufacturing process [12]. Low-carbon cement alternatives – such as Terra CO2 – are able to reduce CO2 emissions by up to 70%. Earlier this year, Brimstone became the world's first producer of carbon negative Portland cement, sequestering carbon through a magnesium species by-product. Other carbon negative alternatives to conventional concrete and steel include a range of bio-based materials. The cumulative total carbon storage of bio-based building structures between 2020 and 2050 could range from 7-60 Gt CO2 depending on the floor area per capita [13]. If combined with material recycling and reuse at deconstruction, the temporary carbon storage provided by bio-based materials could extend beyond the building's useful lifespan, transforming buildings and cities into carbon sinks.

Accelerating embodied carbon regulation has seen investment into green building materials grow rapidly over the past five years. In 2022, over 70% of investment was concentrated in low carbon cement solutions (A/O analysis), where alignment with existing manufacturing and construction processes enables supply to scale quickly. In the next five years, supportive regulatory frameworks will spur significant growth in bio-based materials.

For example, from 2025 a quarter of public construction in France must be bio-based, increasing to half by 2030 [10]. While demand is certainly increasing, challenges remain in ensuring reliable and sustainable supply. To date, mass timber has seen the greatest market adoption, with regulations increasingly permitting mid to high rise structures. However, the spatial mismatch between global sustainable timber supply and future construction demand [3] means that a range of materials beyond timber will be required. In most markets, fast growing materials with high yields – such as bamboo, straw and hemp – present significant potential to satisfy a large component of future construction demand.





Overcoming Risk Averse Mindsets
In Construction

Cost uncertainty, absence of clear certifications, and risk of losing insurance cover serve as key hurdles for project teams looking to integrate novel and green materials. These factors are only exacerbated by the AEC sector's risk aversion, poor digitisation and low levels of standardisation.

Risk Aversion To New Technology

The construction sector's sensitivity to economic cycles has led to low capital investment and limited verticalisation [16]. This in turn creates a reliance on a hyperlocal, temporary workforce that changes between projects. Such complex liability structures make it difficult to introduce new technology and disrupt standard industry practices.
i.e. Building information management (BIM) software Revit is often a contractual requirement for architects, leaving little room for new and improved technologies.

No Two Sites Are The Same

The heterogeneity of site conditions, regulations and project briefs create a need for customisation and specialised, local expertise. This is particularly true for green building design and construction, where a constantly evolving regulatory landscape requires highly specialised skillsets to produce compliant designs capable of meeting the same durability and fire resistance as traditional construction.

Data Siloes

Short term, project based partnerships and complex risk structures prevent data sharing between parties. This sustains significant data silos across the value chain, with specialised knowledge not integrated within design software. *i.e. Procuring green materials without integrated carbon and pricing data makes it difficult to quickly benchmark the performance of traditional materials against green alternatives.*

European Cities Are Paving The Way

Amsterdam

1. *HAUT* is a 73m tall residential building designed by Team V Architectuur and Arup as a hybrid timber-concrete structure. The building has half the carbon emissions relative to traditional construction.
2. *Mandela Buurt* is a timber neighbourhood that is being built in the south of Amster-dam, with 80% of the homes set to be affordable. Construction will begin in 2025, for completion by 2060.
3. Regulations require 20% of new housing in Amsterdam to be constructed from wood or other bio-based materials from 2025.

Paris

1. In France, the RE2020 bill will require dynamic LCAs for all building types from 2023. Dynamic LCAs favour materials that actively store carbon, with the RE2020 also containing incremental carbon caps.
2. From 2025, 25% of materials in public buildings in France will need to be bio-based, increasing to 50% by 2030.

Helsinki

1. *Wood City* is a timber neighbourhood in Helsinki that is under construction. The scheme is comprised of residential, office and hospitality buildings, and is set to be completed by 2024.

Green ConTech We Need At Scale

The optimisation and automation of design, procurement and construction practices will prove critical to scaling the use of green building materials in the mass market.

Designing For Material Efficiency

Next generation design software optimises architectural and engineering workflows by integrating real time carbon, pricing and other specification data into the earliest design stages. Emerging solutions automate design and engineering documentation workflows, de-risking the use of green materials for non-experts.

SWAPP SPECKLE cove.tool

- Generative design
- Documentation automation
- Manufacturer integrations

Sourcing Greener Materials

Green procurement solutions enable project teams to meet increased regulatory requirements for lifecycle assessments by benchmarking traditional polluting materials against green or recycled alternatives. Emerging solutions integrate with design software, material marketplaces, tendering platforms and just-in-time material delivery services.

TIMBERHUB Vizcab Concular

- Lifecycle assessments
- Digital procurement
- Material marketplaces

Prefabrication 2.0 And Robotics

Next generation prefabrication and 3d printing robotics standardise construction processes while enabling highly diverse building outputs. By integrating with existing manufacturing supply chains and design software, Prefab 2.0 startups make it easier for non-experts to design using green materials and prefabricated components.

Mighty Buildings 011h juno

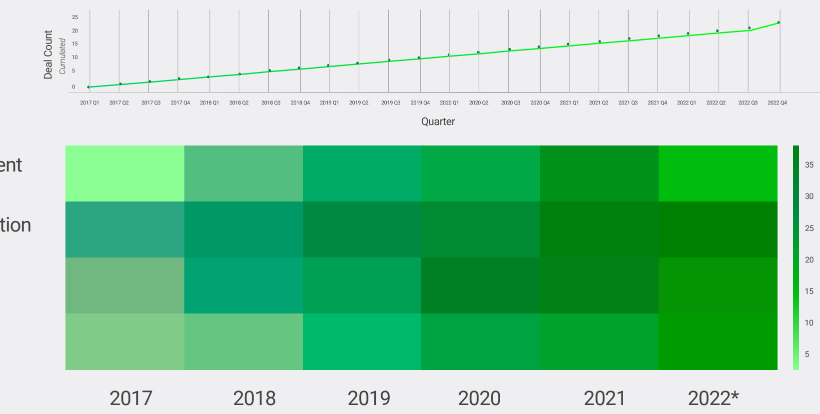
- Scalable prefab
- Bio-based prefab
- Zero waste 3D printing

At A/O, we have already made several investments in startups addressing these challenges and will continue to make many more. Our investments in Vizcab, 011h and Saqara support architects, developers, contractors and investors in implementing green materials and construction methodologies, and will over time inform the underwriting, pricing and regulatory initiatives of a broader ecosystem of stakeholders, including regulators, municipalities, insurers and lenders. This report forms part of an ongoing A/O series covering emerging built world technologies. In this report, we outline emerging climate tech solutions for the construction sector and detail early stage investment activity.

Green ConTech Reaches Record Investment

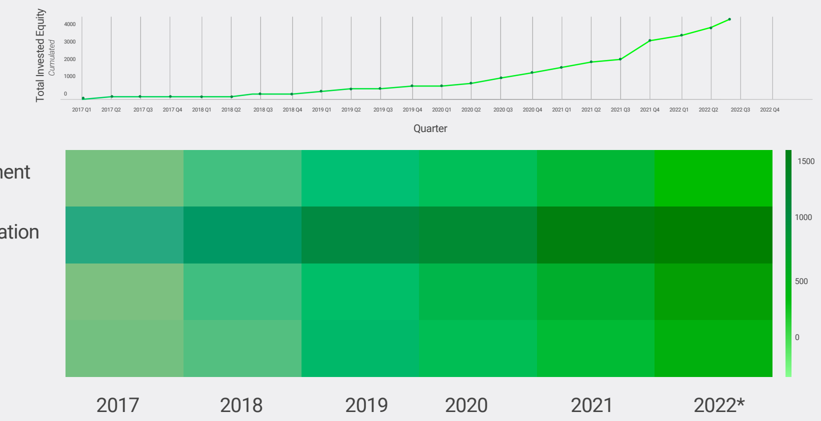
Over the past five years, more than $4.5bn of early stage capital has been allocated to green building design, materials, procurement and prefabrication technology. In 2022, investment in the space is expected to exceed $2.2bn for the first time.

Deal Volume Suggests Further Growth



Investment growth is seen across the board, with later stage capital concentrated in mature Prefab 1.0 companies.

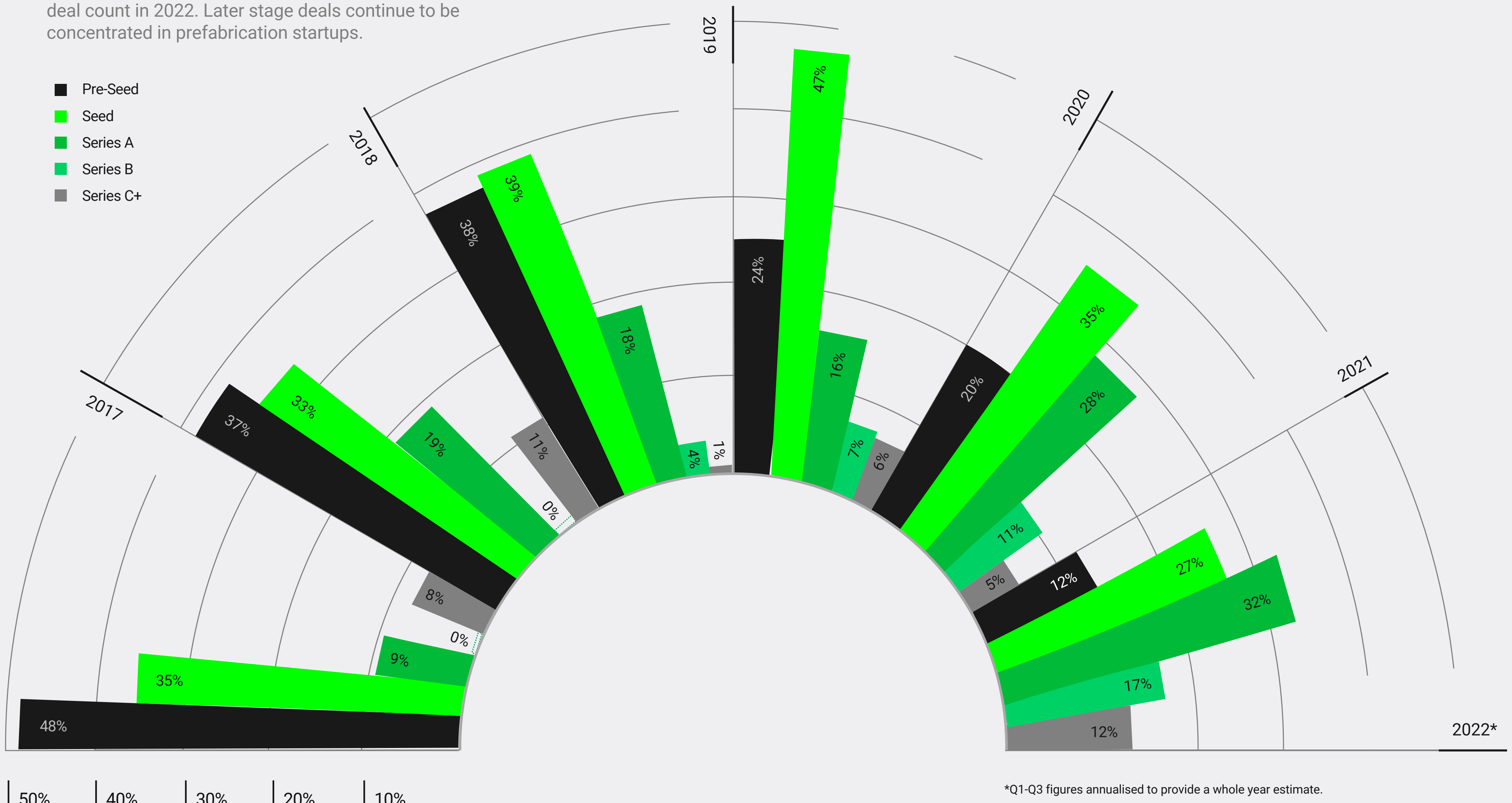
Invested Capital Doubled In 2022



As Prefab 1.0 companies continue to mature, deal growth will be driven by early stage design and procurement solutions.

Series A/B Deals Dominate Deal Flow

Growth in investment volumes is met with the gradual maturation of the green construction tech segment. The average deal profile has shifted from Pre-Seed/Seed to Series A/B as startups in the space demonstrate proof of concept. Close to 40% of deals are Pre-Seed/Seed in 2022, down from more than 80% in 2017. Meanwhile the proportion of Series A/B deals has increased from less than 10% in 2017 to nearly half of total deal count in 2022. Later stage deals continue to be concentrated in prefabrication startups.



*Q1-Q3 figures annualised to provide a whole year estimate.

+$4.5b
Early stage capital allocated to green building design, materials, procurement and prefabrication from 2017-2022

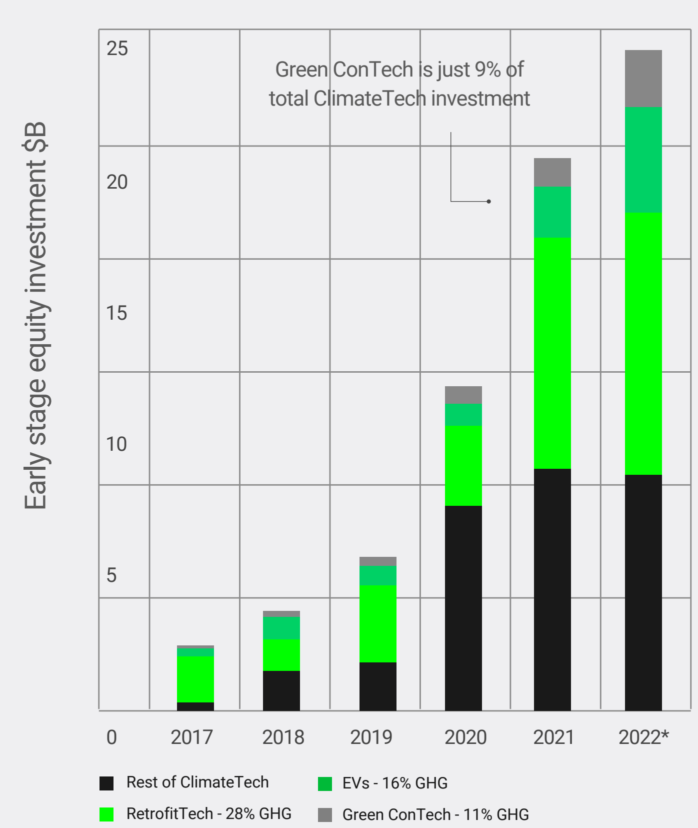
84% CAGR
Compounded annual growth rate (CAGR) in investment volumes from 2017-2022

+$2.2b
Early stage capital invested in 2022 alone

+450
Deals

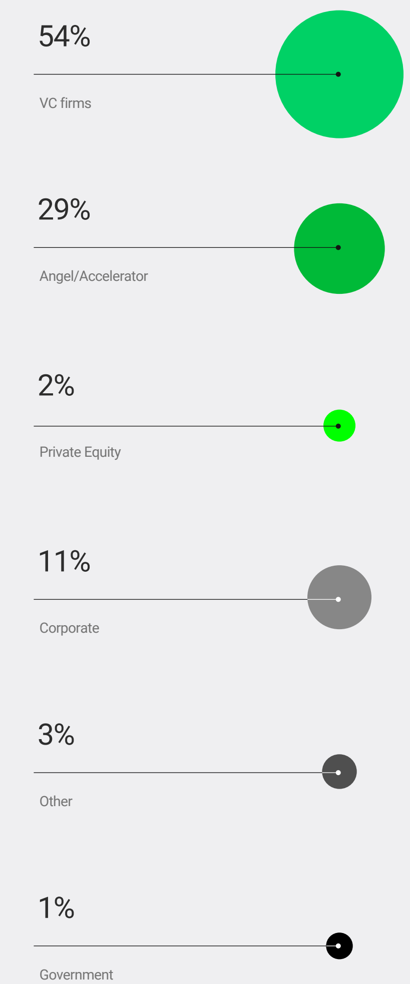
More Funding Is Needed

Investment is mismatched with greenhouse gas (GHG) emissions.



Active Green ConTech Investors

Angels, accelerators and venture capital firms make up the bulk of active investors.



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Designing For Material Efficiency

Design is the most important factor in determining GHG emissions over a building's lifetime. By the time the construction process begins, the majority of decisions affecting a building's lifetime emissions are locked in. As client preferences shift towards the total cost of ownership, design automation will empower architects to have greater agency to prove the value of their designs, accelerating green construction in the mass market. For architects, the adoption of automation tools will be driven by labour shortages and low margins. Automation will augment architectural workflows, and while traditional risk structures in the industry will persist, architectural firms will become more streamlined with a greater representation of practitioners working inhouse at developers or manufacturers.

Design Automation Will Democratise Access to Green Materials

The architectural software market is ripe for disruption, with rapidly rising software costs -- 70% from 2015-2019 [17] and 15% in the year to 2021 -- fuelling outrage across the profession towards AEC software giant Autodesk. Architects' frustrations are certainly justified, given increased costs appear to be met with declining productivity. With gross margins as low as 9%, nearly two thirds of an architecture firm's operational costs are spent on labour [18].

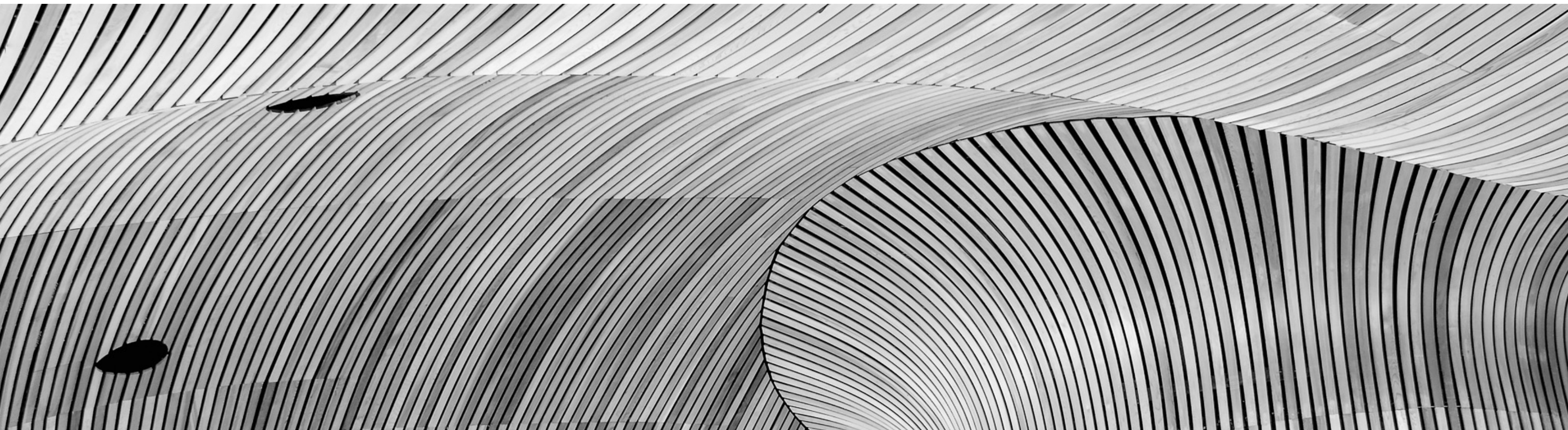
As buildings have grown in complexity, technology has been used as a tool to keep pace rather than to innovate, to digitise previously manual processes rather than to automate core aspects of the design workflow.

Complex building regulations, limited access to product data and a scattered ecosystem of green building products make it difficult for architects to maintain code compliance and avoid greenwashing claims. Currently, the industry relies on a range of experts, who are not only expensive but in short supply.

Experts are typically engaged on bespoke projects, where a clear climate mandate from the developer prices in any additional consultancy costs or ensures a specialist architectural firm is engaged from the outset. In the absence of larger budgets, conventional value engineering practices in the mass market see architects' initial product specifications swapped out for cheaper alternatives with often much worse environmental performance.

$183m

of green construction tech investment was allocated to next gen design software in 2022, 2.4x YoY.



In recent years, there have been a growing number of early stage startups seeking to disrupt various aspects of the architectural software stack.

Green materials can be standardised through prefabrication systems. This significantly de-risks application for generalist architects, reducing the need for specialised skillsets and minimising the risk of value engineering. However, designing with prefab brings other challenges.

While architects design a building's structural system pre-permitting, prefab system specifications traditionally occur post-permitting. This means that architects working on a prefab concept design are forced to build in large tolerances to account for the unknown variation in system specifications.

In turn, significant inefficiencies are created later down the line, as designs often have to be painstakingly reworked once the prefab system is selected. Integrating performance analyses, embodied carbon data and prefabricated design system specifications within architectural software will empower architects to have greater agency to prove the value of their designs, reduce the reliance on specialised skillsets, and improve the efficiency of architecture firms.

Next Generation Design Software

Making a mark in architectural software is not without its challenges. A highly concentrated ownership structure (Autodesk holds 90% market share) is met with a customer need for a diverse set of software solutions on any given project.

This requirement is due to the varying complexity of project design and a generational gap in technical skillsets among architects. Among the most technical users are computational architects – typically BIM consultants in larger firms – who use complex visual programming tools such as Grasshopper and Dynamo to code custom shortcuts or add-ons for the wider firm.

At the other end of the spectrum sit inhouse architects at housebuilders or prefab manufacturers, who use architectural software to produce near identical building designs. For this reason, documentation can often be generated through predefined Autodesk Revit blocks alone.

The disparity in technical skillsets and complexity of learning new design software makes it impractical to train entire generalist architectural teams in the 'latest' solution.

At the same time, contractual requirements to use Autodesk Revit can leave architects little agency to implement directly competing products. For this reason, plugging into one gap in the existing workflow today tends to provide industry disruptors with the best entry point (and ample market opportunity) from which to scale automation throughout the wider design process.

Interestingly, the last couple of years have seen a spike in funding for next gen design startups, with investment jumping from 2% of green construction tech allocation in 2017, to 8% in 2022. At A/O, we see next generation design software as both a key growth segment and critical decarbonisation enabler within the wider landscape of built world technologies.

Interoperability Creates
The Bedrock For Automation

Poor interoperability between existing software products creates tedious rework to manually update models one by one. Given up to 70% [19] of architectural work is carried out on a fixed fee basis, rework is often at the architect's expense. Long hours, tedious workloads and unpaid overtime contribute to an acute shortage of skilled workers in AEC, which is only exacerbated by a growing demand in green material expertise. To date, the industry has relied on open source collaborations between incumbents to improve interoperability. For example, Rhino.Inside -- a collaboration between Autodesk's Revit and McNeil's concept design tool Rhino -- enables architects to design in Rhino from within the Revit platform.

Next generation platforms are providing interoperability across the wider AEC software ecosystem. For example, Speckle's inter-AEC software connectors enable updates from one design model to be reflected in another in real time. Integrations extend across a number of AEC programmes and gaming engines, including Unity and Unreal. For architects using Speckle, the platform significantly reduces manual design rework, enables inter-party tracked changes, and reduces the frequency of clashes between architectural, MEP and structural inputs.

Generative Design Enables
Better Performing Buildings

Recent years have seen environmental performance simulation become integrated within concept design software. This provides a dynamic, near real time insight into a proposed design's future lifecycle impact.

For example, browser-based tools such as Cove.tool enable architects to upload a design model and quickly receive detailed performance analysis data across carbon, daylighting, wind, water, density and cost. We have seen two emerging approaches. On the one hand, performance analyses are integrated within generative design software, with AI-generated massing and layouts optimised for environmental performance.

In practice, the overly simplified user interfaces and limited user controls that these solutions provide sit at odds with the iterative and creative design workflow – aiming to standardise and replace the most custom aspect of building design. Other approaches – including Generate – augment architectural workflows, using AI to enable creativity assistance. The greater flexibility provided empowers architects to tune the degree of automation and consider a range of carbon and cost data points in real time.

Automated Documentation
De-risks Green Building Design

While the concept design stage comprises the most creative aspect of the architectural workflow, detailed and technical design stages represent the bulk of an architect's fee (45-75%) and project time (70%) (A/O analysis). When it comes to prefabricated systems, multifamily, educational and healthcare buildings, unit-based designs make it possible to autonomously optimise technical design and engineering workflows.

70%

of architectural work is carried out on a fixed fee basis

For example, emerging software platform SWAPP automates the tedious process of transforming an architectural design into a fully constructable building. By ingesting a number of architectural models and other datasets, the platform uses AI to optimise for custom architectural constraints, generating a BIM model and associated construction documentation with near complete accuracy.

Automated design documentation extends beyond architectural workflows. Platforms – such as Augmenta -- automate MEP and structural design. These solutions allow users to not only identify clashes between AEC datasets, but automatically resolve clashes through predetermined hierarchies. This is no easy feat given MEP optimisation alone relies on a range of unique parameters, including engineering calculations, product specifications, energy optimisation based on placement and specifications, and maintenance considerations.

Striking the right balance between useability and flexibility will be key to realising mass market adoption of architectural automation software. This is due to the wide range in technical skillsets between architects. Platforms -- such as Hypar -- target a firm’s computational architects, for whom flexibility and platform extensibility is key.

A small but growing market, computational design will prove critical for enabling architectural automation in the long term.

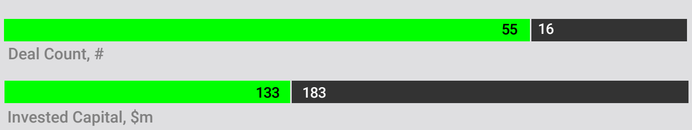
Other platforms -- such as SWAPP -- combine a highly technical infrastructure with the ability to serve a non-technical audience (generalist architects) today. This provides immediate value for a large share of the current market, while retaining the option to open up the platform to computational architects later down the line.

Manufacturer Integrations Boost Prefabrication

Long term, automated design documentation will extend to the onboarding of structural and facade system manufacturers. This will enable generalist architects to: (i) quickly and accurately create buildable designs using green material prefabricated structures, such as mass timber; (ii) quickly and accurately optimise MEP and structural engineering with the chosen structural system; and (iii) extract highly accurate pricing and carbon estimates in real time.

Design

■ 2017-2021 ■ 2022



Invested capital increased 2.4x YoY to 2022 and grew at a 142% CAGR, 2017-2022
Deal count grew by 1.1x YoY to 2022, representing a 18% CAGR, 2017-2022

SWAPP
GENERATE
Augmenta
HYPAR

“Regarding construction, decarbonization depends on using alternative structural materials like certified timber, passive design principles, and renewable primary energy facilities.

That comes at a cost. And the only way to offset extra costs and make it scalable is by simplifying and standardizing end-to-end processes and automating them as much as possible while preserving flexibility and creativity. Enabling this requires the enforcement of software, data and AI along and across the entire value chain.”

Lucas Carne
Co-Founder, 011h

Sourcing Greener Materials

The adoption of design automation software and prefabrication will see a growing share of structural and façade system procurement determined much earlier in the project lifecycle. For other materials and products that continue to be procured hyper-locally, embodied carbon regulation will drive demand for benchmarking solutions that enable non-experts to directly compare one material against another. While procurement today remains highly manual, short term efficiency gains realised through digitised workflows will reduce onsite material waste caused by delays or last minute redesigns. As regulatory pressure increases, the adoption of benchmarking solutions will in turn support the value proposition of material marketplaces in construction.

Digital Procurement Reduces Onsite Waste

Today, construction and demolition waste accounts for nearly 40% of all solid waste in Europe and the US [20] [21]. While material recycling and recovery rates vary significantly between regions, recent years have seen a number of governments mandate incrementally higher thresholds. In the Netherlands, for example, recycling and recovery rates are now as high as 90% [22].

Yet, despite this, just 8% of the Dutch built environment's material use comes from secondary sources. This is due to downcycling, whereby the majority of recycled material is used as aggregate for backfilling roads or other infrastructure. Poor material repurposing rates are seen in other markets too – globally, as much as 98% of construction materials are downcycled [23] [11].

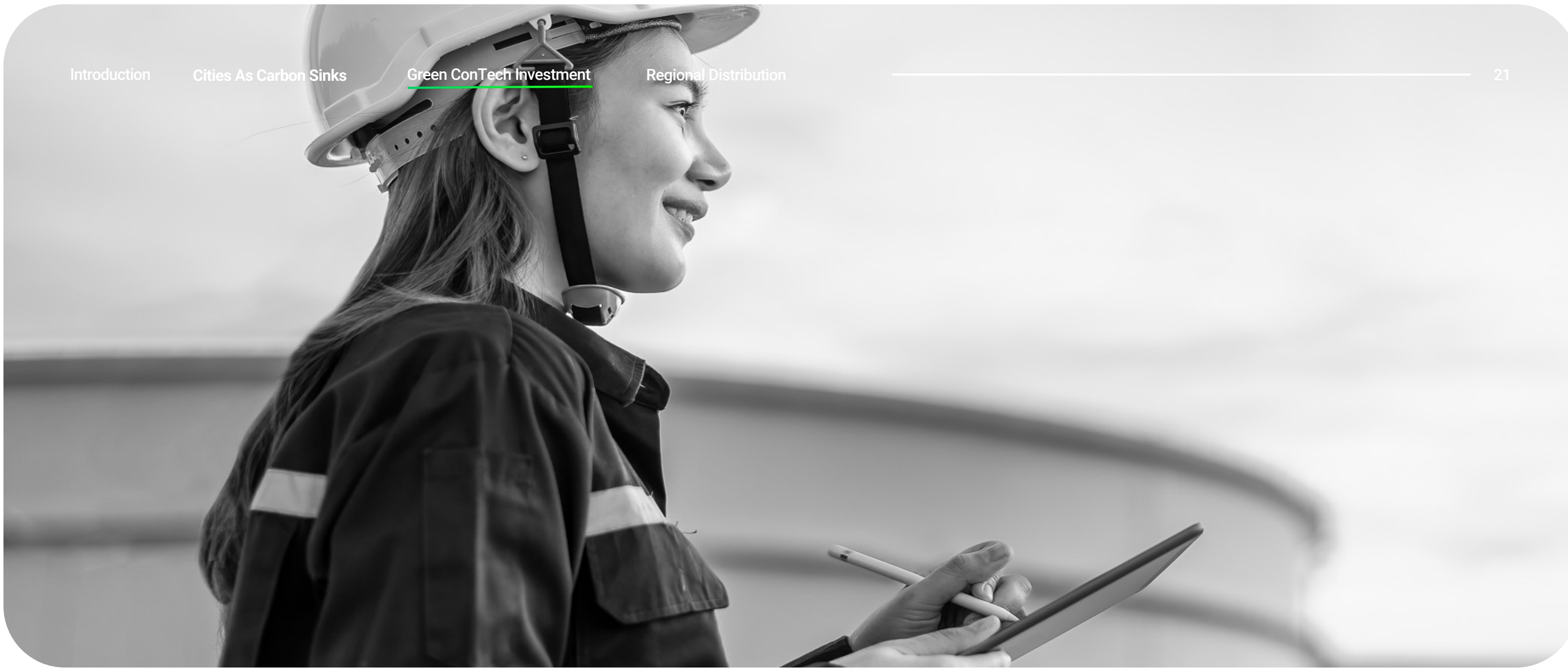
Finding effective ways to reduce onsite waste, directly compare materials, and increase repurposing rates will be critical for minimising embodied carbon in new developments.

Investment in green procurement technology has accelerated in recent years, growing at a 69% CAGR from 2017-2022. In the context of wider green construction technology investment, however, the segment remains nascent, receiving just 3% of investment in 2022. Low investment volumes in green solutions can be explained by low digitisation in procurement workflows as a whole.

Amid a complex and fragmented stakeholder landscape -- including general contractors, material distributors, stockists and subcontractors -- workflows remain predominantly manual. While investment dollars continue to flow into the digitisation of purchasing, logistics and payments workflows, currently only a small subset of allocation targets material benchmarking, repurposing or waste reduction.

$60m

of green construction tech investment was allocated to green procurement solutions in 2022, 0.4x YoY.



As prefabrication systems and components become increasingly integrated within early stage design software, decision-making will be moved further upstream to less fragmented and more sophisticated buyers. In this way, a larger proportion of materials will be procured centrally, with manufacturers able to sell directly to projects. Despite this, a large component of material purchases will continue to occur downstream, relying on local availability and site-level management. This is because certain aspects of construction – such as foundation works – do not facilitate standardisation and the nature of construction financing makes it untenable to pre-purchase all materials ahead of time. The rising adoption of just-in-time delivery platforms – such as Schuettflix and Renorun – enable materials to be delivered to site in a matter of hours. The added flexibility these platforms provide not only reduces the need for material overspecifications, but reduces wastage caused by last minute design deviations or other project delays.

Material Benchmarking
Enables Emissions Reporting

In the absence of direct cost or labour savings, momentum in green procurement technology will be driven by the enforcement of embodied carbon regulation. As EPDs, LCAs and carbon caps become requirements in the next five to ten years, it will become essential for pricing, carbon and other specification data to be integrated within the procurement process. The growing requirement for EPDs and LCAs in a number of markets has already seen the emergence of LCA solutions – such as One Click LCA, Cercula and A/O portfolio company Vizcab – as well as material benchmarking tools, such as Firstplanit and Tangible Materials. These benchmarking tools not only prove critical for carbon reporting, but enable non-experts to make greener decisions faster and more accurately. Other approaches include Bimmatch, which connects a benchmarking tool to an existing BIM model.

As a growing number of materials and products are added to these platforms, architects and other project stakeholders will be able to directly compare products across an entire range of data points, from carbon intensity and price to regional certifications. Over time, the outputted data for a given project will begin to feed into tendering platforms – such as A/O portfolio company Saqara – to enable contractors to meet clients emissions reporting requirements.

Material Marketplaces
Aggregate Green Materials

Long term, regulation enforcement could see benchmarking tools support the adoption of open material marketplaces, whereby products from multiple suppliers are aggregated via a single storefront. This would mark a shift away from current procurement workflows and existing stakeholder dynamics.
At present, material manufacturers do not hold direct supplier relationships with construction buyers, with strong pre-existing relationships between contractors and subcontractors difficult to dislodge. For this reason, stockists and distributers of commodity or low-differentiated products have been resistant to joining open marketplaces.

To date, the aggregation of material suppliers has instead been seen in closed platforms, whereby large developers or general contractors select a preferred vendor network based on pre-existing relationships and enable a range of select suppliers to tender for a given project. Other approaches include Shopify-like storefronts for suppliers, including Brokrete, and AI-assisted tools for material purchases, such as Parspec. As embodied carbon regulation drives the adoption of material benchmarking, the value proposition of open material marketplaces will increase.

This could be particularly true for green materials and products. Current under-developed supply chains, complexity in regional certifications and a requirement to ensure supply chain traceability could provide a unique entry point from which to override existing dynamics and aggregate material supply. For example, specialised marketplaces such as Timberhub are enabling prospective buyers to verify that the purchased timber has been sustainably sourced.

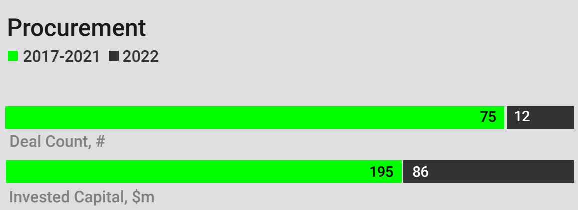
Material Documentation Supports the Circular Economy

Transforming buildings and cities into long term carbon storage devices will rely on the repurposing of carbon negative materials. Without material repurposing, any sequestered carbon is released at the end of the building's lifecycle. A growing number of early stage companies are enabling asset managers to document the salvage potential of a completed building and consider optimum pathways for deconstruction. Material documentation solutions -- such as Madaster -- enable the materials and products in a building to be registered post construction, via so called 'material passports'. Material passports improve the ease at which asset managers can extract insights about a building, including granular specification data and sequestered carbon. Other platforms -- such as Adaptis -- enable asset managers to evaluate options for deconstruction. Through analysing existing building conditions and generating automated material salvage values, the platform provides a number of deconstruction and adaptation feasibility design options.

When it comes to material reuse, today there remains a fundamental supply gap. As mandates for material reuse grow, we expect to see the development of new business models and value chains that can process and transform recovered materials to repeatable and standardised SKUs at scale. This will be critical for ensuring certainty over volumes and supply chains, facilitating broader market adoption. Once supply is sufficient, adoption will be driven by material benchmarking tools that will enable stakeholders to directly compare the specification of recycled materials relative to new materials.

3%

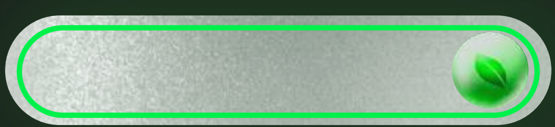
Green procurement solutions received just 3% of green construction tech in 2022. More funding is needed to improve access to greener materials.



Invested capital increased 0.6x YoY to 2022 and grew at a 71% CAGR, 2017-2022
Deal count grew by 0.5x YoY to 2022, representing a 15% CAGR, 2017-2022.

Vizcab
Saqara
CIRCULARISE
TIMBERHUB

“In a few years, every building will have a carbon budget, i.e., an upper limit of carbon emissions.



Moreover, this carbon budget will decrease over the years to come until we reach carbon neutrality in 2050. In other words, without data, you can’t understand and anticipate the impact of this carbon budget on your company, whoever you are.”

Thomas Jusselme,
Co-Founder, Vizcab

Prefabrication 2.0

Amid a chronic shortage of skilled labour, prefabrication serves as a critical enabler of green construction. A new modular wave is leveraging kit-of-part panelised systems to standardise green construction processes while retaining highly diverse design outcomes. For urban environments, next generation design systems are enabling mid-rise and high-rise green construction. And when it comes to developing green housing schemes on the fringe of cities or in rural locations, 3D printing robotics are enabling the near autonomous construction of single family homes.

Prefab 1.0

Lessons Learned

Prefabrication in construction is nothing new, however industry adoption continues to be slow. One explanation for this is the poor perception of prefabrication by the wider construction sector, particularly when it comes to product quality and ease of implementation. An initial wave of venture backed prefabrication companies – Prefab 1.0 – promised to realise significant time and cost efficiencies, yet almost consistently failed to deliver at scale.

Nascent regulatory and insurance frameworks have undoubtedly slowed the adoption of prefabrication. But this has only been exacerbated by Prefab 1.0’s extreme focus on product standardisation and ultimate misalignment with existing workflows and supply chains.

A clear example is Katerra, which having raised over a billion dollars to deliver an end-to-end prefabrication solution, ultimately fell short on execution [24].

A new generation of modular companies – Prefab 2.0 – are addressing Prefab 1.0’s limitations. By focusing on process standardisation in place of product standardisation, Prefab 2.0 startups leverage kit-of-part panelised systems and highly localised supply chains to deliver diverse end products. There are many benefits to this new approach, from greater alignment with traditional design and construction practices (improving the ease of adoption for generalist project teams) to de-risking novel construction methods (enabling faster insurance and certification processes).

Prefab 2.0
A New Modular Wave

To date, investment dollars in green construction tech have been highly concentrated in prefabrication companies – representing as much as two thirds of investment from 2017-2022. Within prefabrication, investment volumes have been driven by the maturation of Prefab 1.0 companies. Meanwhile, Prefab 2.0 innovation and the rise of 3D printing robotics are driving early stage deal volume.

Process Optimisation
Enabling Speed + Scale

A key differentiator between Prefab 1.0 and 2.0 is the integration of prefabrication systems within architectural software, which generates time and cost efficiencies. For project teams that choose to adopt prefabrication post-permitting, design plugins enable architects to more easily convert a traditional building layout to the manufacturer's kit-of-parts system. And for project teams where the use of prefabrication has been determined during the project's earliest stages, design plugins enable architects to create layouts that comply with the prefabricated manufacturer's structural system from the outset.

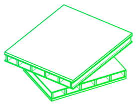
Design integration feeds into both verticalised and distributed Prefab 2.0 models. For highly verticalised models – such as Plant Prefab and Zuru Tech – production is retained inhouse, with design plugins enabling end-to-end control of the design and construction process.

For distributed, asset-light models -- such as Juno and A/O portfolio company 011h -- production is outsourced to manufacturing partners, with design plugins complemented by production facility and onsite logistics software to enable end-to-end process optimisation.

In the long term, multiple prefabrication systems could be embedded within design automation software. This would enable project teams to accurately benchmark a range of prefabrication systems against cost, carbon intensity and other performance metrics. As design automation extends to MEP and structural engineering, there will be increased accuracy of performance estimates and greater streamlining of the end-to-end design process.

When combined with the logistics and supply chain optimisation provided by Prefab 2.0 companies, we could start to envisage the execution of one click buildings – from design through to construction.

As more prefabrication systems are onboarded onto design automation platforms, we could similarly start to see commission or referral fees charged based on the frequency with which a prefabricated system is employed by the architects and engineers using the software.



$1.6bn

of green construction tech investment was allocated to prefabrication solutions in 2022, 2.5x YoY.

Building Bigger + Better
Pushing Structural Boundaries

New materials, manufacturing automation and enhanced digitisation are extending design capabilities, improving precision and boosting productivity in manufacturing. This has significant implications for the integration of green building materials within prefabricated structural systems.

When it comes to timber construction, for example, manufacturing and regulatory constraints have historically limited the material's use in urban environments. Recent advancements in regional building codes across Europe and the US, however, will enable the use of mass timber in mid and high rise building structures. For example, earlier this year, California updated its building code to permit mass timber construction of up to 18 storeys [25].

Regulatory momentum is reflected in a host of Prefab 2.0 startups – including Juno and A/O portfolio company 011h – which are enabling the scaled production of mid-rise mass timber buildings. A scheme completed by 011h, for example, was able to achieve embodied carbon reductions of 90% relative to traditional construction methods. Meanwhile, startups -- including Assembly OSM – are leveraging a distributed supply chain to develop systems for high-rise buildings between 10 and 30 storeys high. In the future, the kit-of-parts system could incorporate mass timber structural components.

Automated Construction
Scaling Green Housebuilding

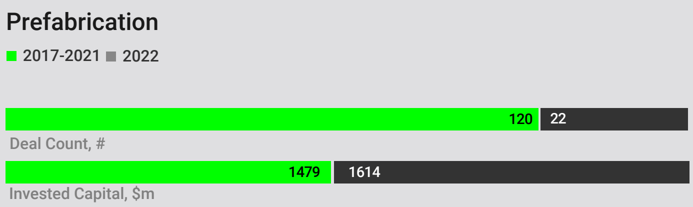
Today, a range of 3D printing robotics solutions are enabling the development of low rise structures in locations with particularly acute labour shortages and underdeveloped infrastructure. This presents a clear solution for the delivery of green, high quality single family housing developments.

Companies – including Icon 3D, Diamond Age and Apis Cor – print structures directly onsite, offsetting up to half the manual labour required to build a conventional home. Given the design model automatically feeds through to the construction output, there is reduced risk of human error. For this reason, the use of 3D printing robotics can reduce the extent of rework required onsite and the associated material waste.

Other solutions -- such as Mighty Buildings – build micro factories located close to site to print kit-of-part components that are later assembled onsite. Earlier this year, Mighty Buildings announced the completion of the world's first 3D printed net zero energy home [26], part of a future scheme of over 40 units. The scheme leverages a low carbon concrete alternative for the exterior panels, with the development containing over 60% recycled materials. Similar applications are emerging beyond housebuilding, with startups including Hyperion Robotics claiming to reduce the embodied carbon emissions of industrial components by up to 90%, through using recycled waste from mining, steel, wood, coal and concrete industries.

$3.0bn

of green construction tech investment has been allocated to prefabrication companies since 2017, representing a 75% CAGR to 2022.

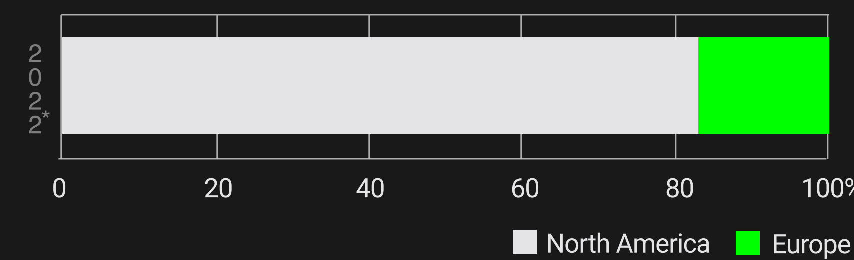


Invested capital increased 2.5x YoY to 2022 and grew at a 75% CAGR, 2017-2022
Deal count grew by 1.0x YoY to 2022, representing a 19% CAGR, 2017-2022

Regional Distribution

In the past five years, capital has been concentrated in North American startups across all segments (84%), while deal count is evenly split between Europe and North America. Given Europe's rapid development of embodied carbon regulation, growth in green design and procurement solutions is expected to remain heavily weighted towards Europe.

Invested Capital North America vs Europe



Top 10 Cities By #Deals Since 2017

Rank	City
01	London, UK
02	San Francisco, CA
03	Tel Aviv, Israel
04	Los Angeles, CA
05	Oakland, CA
06	Vancouver, Canada
07	Las Vegas, CA
08	Paris, France
09	Zurich, Switzerland
10	Oslo, Norway

North America · Europe

Deal Distribution By Vertical

a/o proptech

Methodology

The solutions outlined in this report focus on 2017 to Q3 2022 early stage deal data gathered from Pitchbook. We have identified +200 companies with headquarters in North America and Europe that raised disclosed investment rounds from 2017 to September 2022, and importantly which align with our segmentation of the green construction technology market.

For the capital allocation analysis, we have chosen to focus on early stage equity deals, including: all venture capital deals, angel investments and crowdfunding rounds.

We have excluded: debt financing, private equity, secondary transactions, public offerings and SPACs. Where an investment's deal size has not been disclosed on Pitchbook, we have used Crunchbase data. Where the deal size is not disclosed on either Pitchbook or Crunchbase, we have chosen not to include the deal in our deal count analysis.

Given the rapidly evolving startup landscape, our segmentation of the market relates only to how we at A/O perceive the current state of the green construction technology market.

Acknowledgements

At A/O we pride ourselves on our data-driven approach to venture capital investing. This report is the result of interdisciplinary collaboration across investment, data science and design. If you are a founder or real estate leader tackling building decarbonisation or interested to learn more, reach out to one of our team below. This report forms part of an ongoing A/O series covering emerging built world technologies.

Catriona Hyland
Investment Research Analyst

Catriona focuses on research-driven sector analysis, including the identification of core trends, assessment of market dynamics and evaluation of investment targets.

View profile

Jayasmita Chakraborty
Data Science Investment Analyst

Jayasmita focuses on extracting and analysing company data to automate key tasks as well as conducting technical due diligence to support investment activities while using the latest advancements in data science and software engineering.

View profile

Mounia Essaadani
Creative Director

Mounia is an experienced designer and marketer. She drives branding, content creation, marketing, and social media at A/O PropTech, to enhance the firm's presence and business development objectives.

View profile

Gregory Dewerpe
Founder - Chief Investment Officer

Gregory is one of Europe's leading proptech venture capitalists and a long standing, prominent voice promoting the acceleration of positive transformation in the built world. He founded A/O on the back of a deep understanding of the industry's shortcomings.

View profile

Othmane Zrikem
Chief Data Officer

Othmane is a Technologist as well as a leading PropTech venture capitalist in Europe. Othmane has been notably focusing on ClimateTech and Data Science methods to decarbonise the built world.

View profile

References

[1] UK GBC, "Net Zero Whole Life Carbon Roadmap: A Pathway to Net Zero for the UK Built Environment," 2021.
[2] B. Guneralp, "Global scenarios of urban density and its impact on building energy use through 2050: Datasets," 2017.
[3] IEA, GlobalABC, UNEP, "Global Status Report For Buildings And Construction," 2021.
[4] J. Arehart, F. Pomponi and B. D'Amico, "Structural material demand and associated embodied carbon emissions of the United States building stock: 2020–2100," Resources, Conservation and Recycling, 2022.
[5] Circular Ecology, "The Environmental Sustainability of Existing Buildings: Refurbish or Replace?," 2015.
[6] Urban Land Institute, Financial Times, "Industry body warns on property sector's failure to cut emissions," 2022.
[7] MSCI, "Measuring Climate Risk in Real Estate Portfolios," 2020.
[8] J. Doerr, Speed & Scale, 2021.
[9] Imperial College London, "Greening Cement And Steel: 9 Ways These Industries Can Reach Net Zero," 2022.
[10] G. e. a. Churkina, "Buildings as a global carbon sink," 2020.
[11] Oxford Economics, "Future of Construction: A Global Forecast for Construction to 2030," 2021.
[12] Imperial College London, "Best ways to cut carbon emissions from the cement industry explored".
[13] F. Pomponi, J. Hart, J. Arehart and B. D'Amico, Buildings as a Carbon Sink? A Reality Check on Feasibility Limits, Edinburgh Napier University and Cambridge University, 2020.
[14] F. N. Assembly, Bill nº 5166 aimed at accelerating the development of construction and renovation in wood-earth-straw, 2022.
[15] V. Goswein, "Wood in buildings: the right answer to the wrong question," 2022.
[16] McKinsey, "The next normal in construction," 2020.
[17] Architects Journal, "Under-fire Autodesk tells architects: 'We have fallen short'," 2020.
[18] Royal Institute of British Architects, "Business Benchmarking," 2021.
[19] AIA, "The Business of Architecture 2020," 2021.
[20] World Economic Forum, "Shaping the Future of Construction: A Breakthrough in Mindset and Technology," 2016.
[21] European Commission, "Construction and Demolition Waste," na.
[22] Circle Economy, "Closing the Circularity Gap in the Dutch Built Environment," 2022.
[23] Mckinsey, "Capturing the green-premium value from sustainable materials," 2022.
[24] Wall Street Journal, "How a SoftBank-Backed Construction Startup Burned Through $3 Billion," 2021.
[25] Reuters, "Use of cross-laminated timber may rise in the U.S.," 2022.
[26] Business Wire, "Mighty Buildings Completes World's First 3D-Printed Zero Net Energy Home, Announces B2B Strategy Expansion to Accelerate Growth," 2022.
[27] US Treasury Financial Stability Oversight Council, "Report on Climate-Related Financial Risk," 2021.
[28] B. Guneralp, Y. Zhou and D. Urge-Vorsatz, "Global scenarios of urban density and its impacts on building energy use through 2050," Proceedings of the National Academy of Sciences of the United States of America, 2017.

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