Construction's Coming Productivity Wave

Despite its monolithic size, the $12 trillion architecture, engineering, and construction (AEC) industry has been a laggard in realizing productivity improvements. Construction alone, which comprises ≈13% of global GDP, has only realized a 10% productivity improvement at the aggregate level (roughly 0.4% annually) over the past two decades. Compare this to a 50% (2% annually) productivity improvement realized by the total economy or 90% (3% annually) for the manufacturing sector, according to McKinsey. It can be argued that construction has failed to embrace a technology that significantly boosts productivity since the concrete-mixing truck. However, the construction industry is now turning the page from years of stagnant productivity towards a new era of productivity growth.

In This Report

Today, multiple automation technologies are emerging as novel productivity-boosting tools for AEC. The adoption of automation in AEC is being driven by a shortage of skilled labor, strong demand for infrastructure, lack of affordable housing, the climate crisis, and falling barriers to technological adoption.

This report will focus on construction and argue that the industry is in the early innings of an autonomous revolution set to not only boost productivity but also alleviate some of the largest challenges facing the industry. Key platforms positioned to drive this productivity enhancing wave include AI-powered construction management softwares such as BIM, robots optimized for specific construction functions, ground-based 3D printing, specialized drones across 3D printing and surveying, and on/off-site prefabrication. Although technological adoption in construction has historically lagged other sectors, use cases signaling increasing adoption are rising with encouraging momentum. We will take a dive into the automation technologies and their investment implications below.

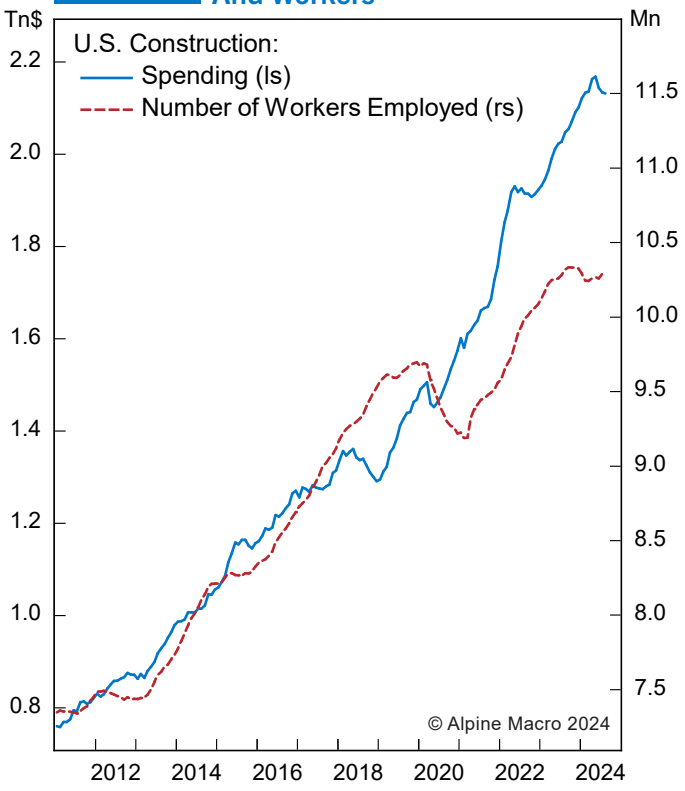
A Setup Ripe For Disruption

Aside from flatlined productivity, a multitude of macro factors are key tailwinds supporting the adoption of automation in construction. Consider the following:

1) **Growing Housing Demand**

- In 2023, the U.S. experienced its largest-ever single-year population growth, with an increase of 3.8 million people.

Chart 1 Growing Spread Between Construction Spending And Workers

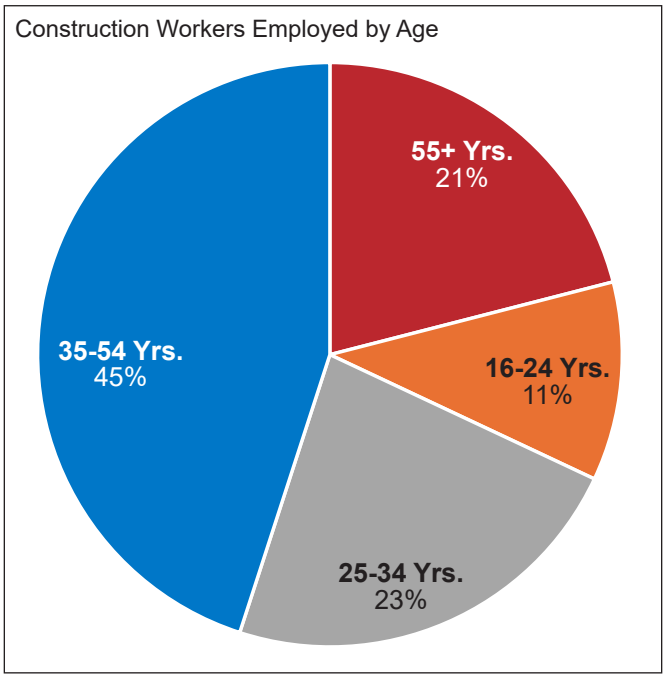


- Millennials, who are entering household formation years, are the largest generation group in the U.S., totaling an estimated 72.7 million.

2) **Dire Construction Labor Stats**

- America's construction labor shortage is highlighted by the divergence between construction spending and employed construction workers (**Chart 1**).
- From July 2015 to July 2024, American construction job vacancies have risen by over 68% from 147,000 to 248,000.
- This year alone, over 500,000 new workers are needed to satisfy housing demand, notes a 2024 report by Associated Builders and Contractors.

Chart 2 Aging Construction Workforce

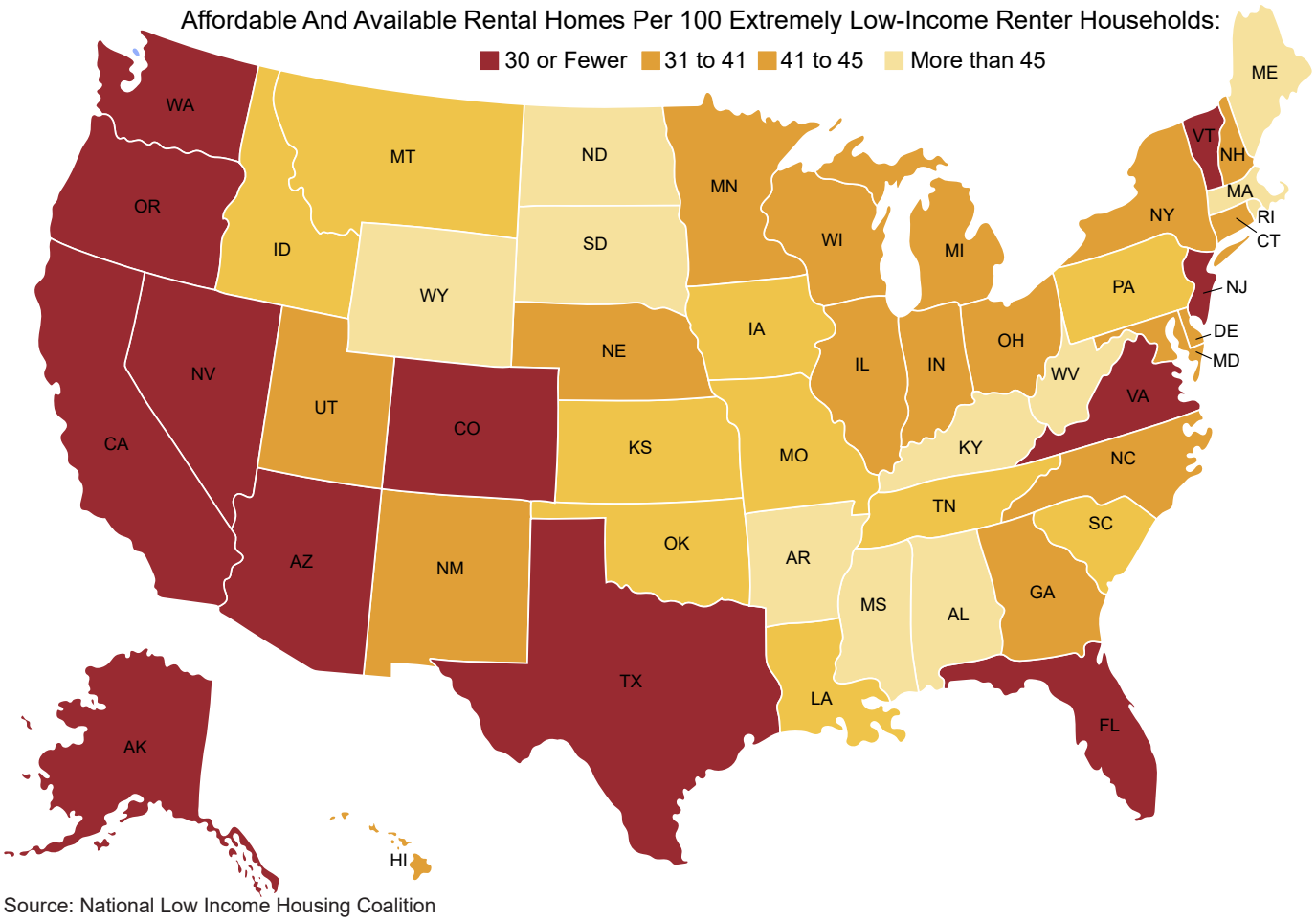


- By 2027, a Bloomberg analysis indicates the U.S. will be short over 550,000 plumbers. Additionally, nearly 30% of union electricians are near retirement.
- Currently, over 20% of the construction workforce is over 55, while 45% is between the ages of 35-54 (**Chart 2**).

3) **Affordable Housing Supply Shortfall**

- The National Association of Realtors notes the U.S. housing shortfall has averaged 5.5 million homes over the last two decades.
- In affordable housing specifically, the National Low Income Housing Coalition estimates that the U.S. shortfall is over 7 million rental homes (**Chart 3**).
- In Canada, an estimated 3.5 million homes are needed, which requires more than double

Chart 3 U.S. Affordable Housing Crisis



Source: National Low Income Housing Coalition

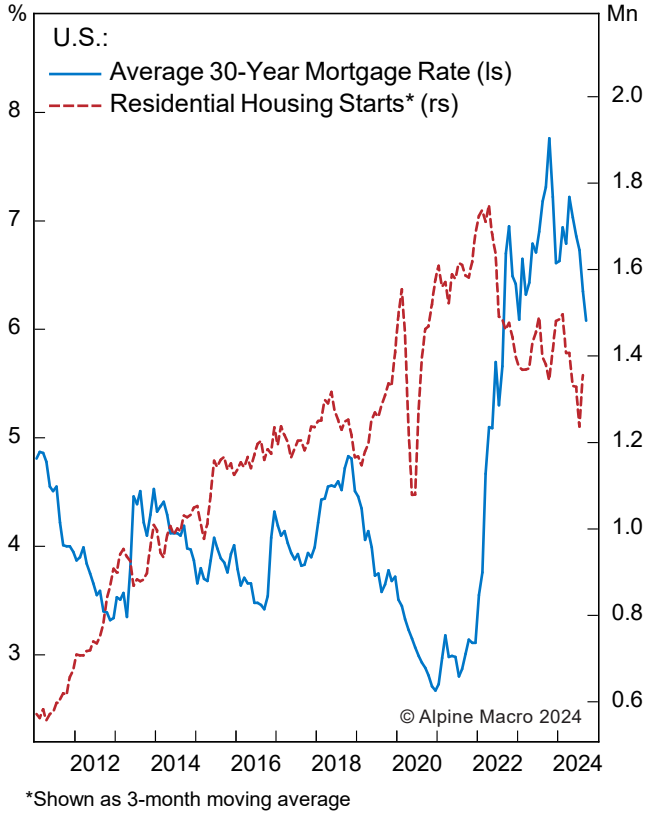
the current rate of construction, according to Canada's National Housing Agency.

4) **Falling Rates To Spur New Home Starts Revival**

- As reflected in **Chart 4**, the drop in rates has already reversed the negative trajectory of housing starts to continue the structural steep rise over the past decade. In August, overall building permits, rose to 1.48 million at a 5% annualized rate. New construction of single-family homes increased nearly 16%.
- It is important to note that large U.S. homebuilding equities have performed well during the Fed's tightening cycle. This positions them with a healthy balance sheet to embrace automation CAPEX. Indeed, D.R. Horton was recently rated A-minus by Fitch Ratings – the first-ever A rating for the sector.

Healthy homebuilder balance sheets are equipping the sector to embrace automation. For example, D.R. Horton is partnering with 3D-printing robots company Apis Cor, and Tri Pointe is a leader in AI software integration across the building process. A survey across 1,000 general contractors in North America, the United Kingdom, and Australia found that 84% of contracting firms are integrating autonomous

Chart 4 Falling Rates Buoying New Home Starts



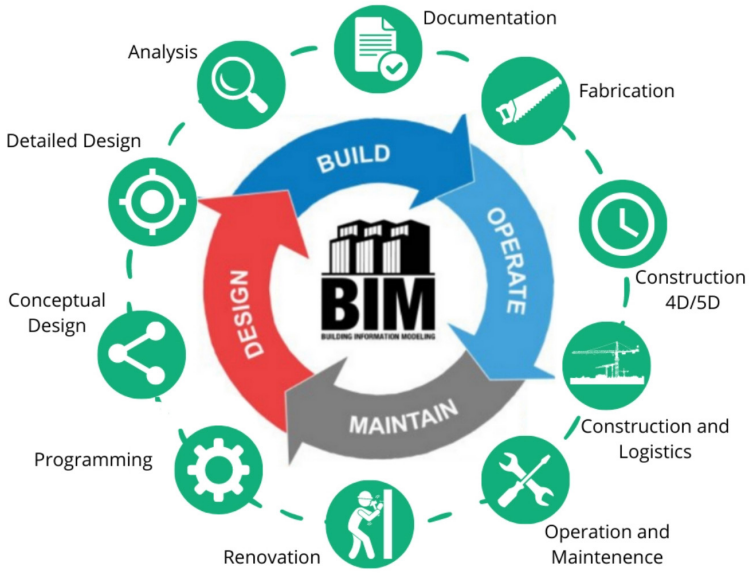
*Shown as 3-month moving average

technology in their operations. Specifically, the survey concluded that 32% of contractors use autonomous product management tools and 16.5% use fully autonomous robots. Large homebuilders are also hopping on the automation train.

AI-Backed Construction Management

Building Information Modeling (BIM) platforms are at the forefront of AI's integration into construction and provide a suite of comprehensive tools throughout the construction lifecycle. Already, BIM is having a tangible impact on how buildings are planned, designed, constructed, and managed. Through building complex multidimensional models and AI, BIM platforms increase construction efficiency

Chart 5 BIM Capabilities



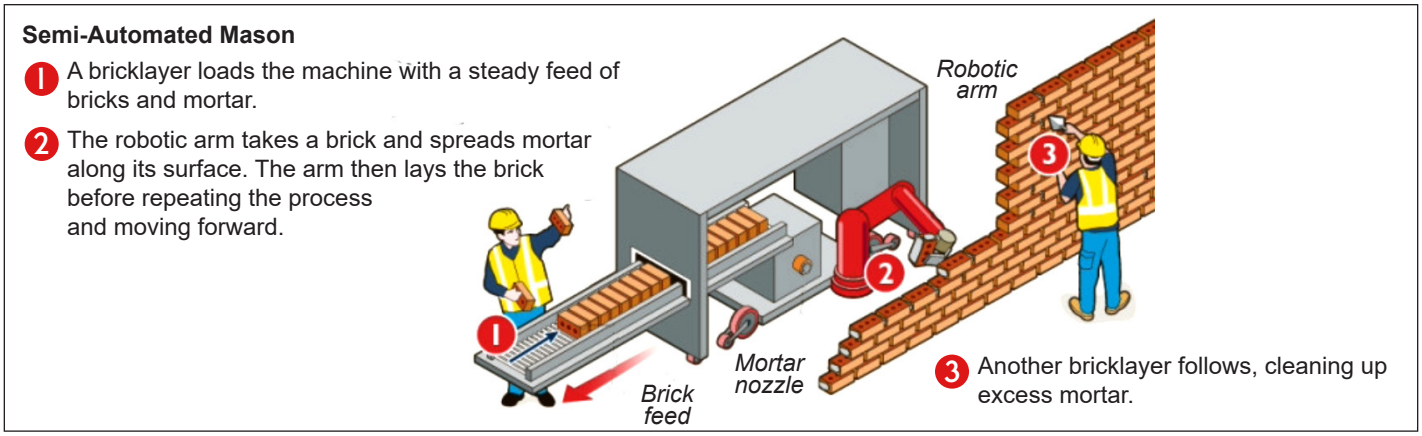
Source: Novatr

(Chart 5). Cutting-edge BIM platforms create a "digital twin", a digital representation of the physical plans of the project.

BIM platforms are the most established automation technology currently impacting the sector with established product offerings. For example, Imerso's platform tracks on-site building progress holistically and uses AI to produce actionable insights for project managers. Aside from accelerating problem solving by 2x, the platform tracks work status, performs quality verification of completed work, identifies hidden errors, and proactively predicts upcoming issues.

Use cases are highlighting the benefits of BIM integration. For example, construction rework and delay costs were cut by 10x on Denmark's tallest building by using Imerso's platform. Imerso's data validates that its solutions cut travel cost by 50% and raise team productivity by 5x. In another example,

Chart 6 Brick Laying Human-Robot Symbiosis



Source: The London Times

Trimble's Construction One's BIM platform is expected to save Precision Concrete six-figures on projects by eliminating unforeseen errors.

Robotic Jobsite Helpers

Various specialized robots are becoming integrated into construction workflows at an accelerating pace. Robots offer improved precision and efficiency, reduce reliance on labor constraints, and improve jobsite safety. The National Safety Council has cited a 20% decline in construction-related accidents credited to robot usage in dangerous construction applications.

Importantly, advancements in sensors and robotic vision systems are unlocking robots' potential by equipping them with a once-absent capability essential in construction – precision. Currently, there are three main types of robots at the vanguard of construction robotics:

i) Semi-autonomous robots leverage a collaborative approach that requires human input but can perform tasks independently. This is highly valuable for labor-intensive repetitive tasks. An example is Construction Robotics' Semi-Automated Mason (SAM) that can lay around 3000 bricks per day (**Chart 6**).

ii) Fully autonomous robots require no human intervention to complete tasks. These robots are equipped with advanced sensors and often follow preprogrammed task objectives. HILTI's Jaibot is fully autonomous and drills holes for electrical installations following a pre-defined pattern.

iii) Teleoperated robots require a human operator but specialize in performing dangerous tasks. Construction Robotics' TyBot is an autonomous rebar-tying robot that performs the dangerous and repetitive task of tying rebar.

While highly nascent, the proliferation of robotics in construction holds the largest potential of unlocking massive productivity enhancements through "human-robot" symbiosis. Robots are the "missing link" to transform a historically labor-intensive industry into one aided by automation.

Use cases are showing massive potential. For example, projects utilizing the SAM100 autonomous masonry machine from Construction Robotics have decreased labor costs by 50% while doubling the speed at which buildings are constructed. Another compelling example is Fast Brick Robotics' Hadrian X, a shuttle block delivery system for bricks. Hadrian X can lay 500 bricks per hour compared to a skilled human bricklayer that lays 300-500 bricks per day. The system boasts a 32-meter telescoping boom arm capable of reaching three stories high and relies on dynamic stabling technology to ensure pinpoint accuracy. The Australian platform has successfully completed the largest project ever undertaken by any automated robotic construction method (a 16-townhouse development) and has recently arrived in the U.S. for a project in Florida.

Ground-Based 3D Construction Printing (3DCP)

Multiple building approaches and innovative materials are positioning 3DCP to play a key role in alleviating the affordable housing crisis. 3DCP construction creates structures layer by layer to increase construction speed, reduce waste, enhance design flexibility, and unlock cost savings.

ICON, a leader in the 3DCP space, can print the walls of a 500 sq.ft. home in just 24 hours and allows customers to fully customize the design of their home using an "AI architect". The company has "printed" a 3,844 sq.ft. barracks for the Texas Military and is completing a 100-home project outside of Austin, Texas. The latter project's home price is $475,000 while the median comparably sized Austin-area home lists for over $800,000. ICON has unveiled a new printing platform named "Phoenix" that can build roofs and foundations. Ultimately, ICON believes Pheonix's operational cost will fall to $3 an hour and will cut 3D-printed home construction times in half (to one week) while also reducing wall cost by 30% compared to traditional methods.

Alquist 3D, another startup in the space, can print the walls for a 1,300-square-foot in roughly 40 hours. Alquist is also printing houses for Habitat for Humanity and recently printed one of the largest free-standing 3D printed structures for Walmart. Walmart tapped Alquist for a 8,000 sq.ft. pickup and delivery site with walls 20ft. high.

Innovative materials are enhancing the strength, sustainability, durability, and environmental impact of 3D-printed structures. These materials are addressing challenges like temperature, humidity, and precipitation during printing. For example, Eco Material Technologies' PozzoCEM Vite eco-concrete reduces concrete emissions by 93% while accelerating set time. Similarly, emerging self-healing concrete alternatives that can autonomously repair small cracks are improving building resiliency and "smoothing out" variability in the printing process.

Drone Builders

Drones (UAVs) offer unmatched versatility in the construction landscape. UAVs are emerging as cost-effective data aggregators for a range of pre-construction tasks. More specifically, UAVs are uniquely positioned to perform aerial inspection and surveying. For example, some fixed-wing drones mounted with cameras and sensors specialized

for surveying can complete a survey 80% quicker and with improved detail than traditional terrestrial surveying methods. Kespry, a start-up in the UAV surveying space, can complete and provide survey-grade field data in 30 minutes.

Aside from pre-construction aerial assistance, UAVs are also being utilized for real time construction monitoring and for aerial additive manufacturing (AAM). Rapid advancements across a range of UAV technologies now allow drones to fly with millimeter-level precision and fly safely with payloads of over 100 pounds. We believe this marks a turning point for UAV adoption in construction as lacking capabilities in accuracy and payload size traditionally hampered UAV adoption. For example, Ageagle, a construction UAV startup, uses their highly accurate eBee X fixed-wing mapping drone to provide contractors with building data during construction. The drone provides data down to 3cms in accuracy to generate geo-accurate 3D building models in real time. Specialized drones like eBee X can be flown into parts of construction sites that humans simply cannot access, providing highly valuable insights.

AAM, or drone-based 3D printing, marks the cutting-edge of UAV applications in construction. "Builder UAVs" are not confined to the limitations of ground-based 3D printing and can work as a "team" during the building process with specialized individual task. This approach follows a closed-loop system that was illustrated at the Imperial College London. AAM showcases collaboration between "BuilDrones" that extrude building materials in-flight and "ScanDrones" that continually track progress to communicate upcoming manufacturing steps back to the "BuilDrones".

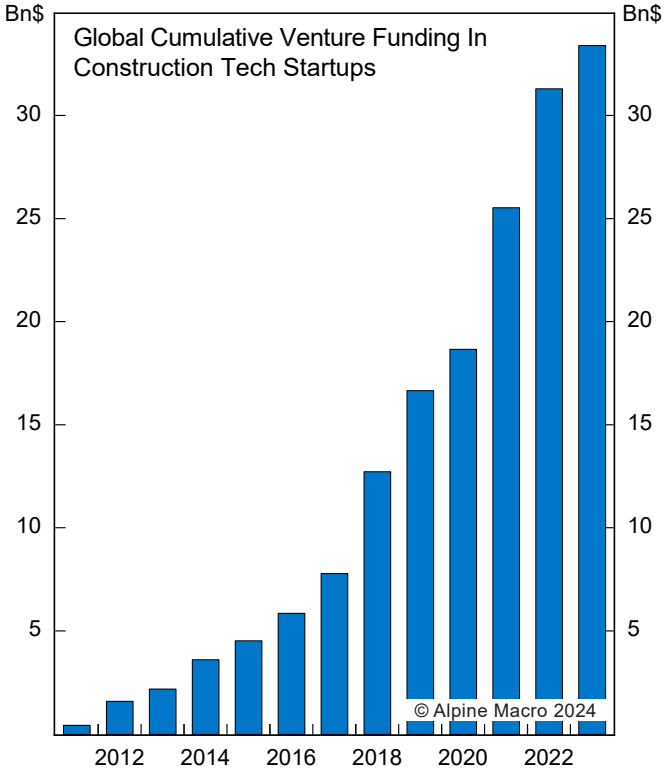
Autonomous Prefabrication

Autonomous technologies are unlocking new possibilities across on/off-site modular prefabrication. A McKinsey analysis highlights the benefits of modularity, showing the technique can accelerate completion timelines by 20-50% while slashing costs by 20%. Modular construction is also much greener than traditional methods, offering a 30% reduction in emissions from energy use, and a 60% emissions reduction from materials and worker transportation. Currently, only 4% of homes in the U.S. are built using modular construction, compared to 15% in Japan and 45% in Finland, Norway, and Sweden.

Considering the construction labor shortage, robots and automated machining are essential to boosting modular construction output. Novel AI "libraries" are emerging that equip widely accessible off-the-shelf robots with modular construction "know-how". Promise Robotics is creating a comprehensive AI platform with a robust "library" of construction tasks across various materials and assemblies. The goal is for standard industrial robots to autonomously produce customized modular components, resembling "Lego" pieces, for home construction. The platform orchestrates off-site factory operations, logistics, and services for rapid fulfillment and ships out for on-site assembly.

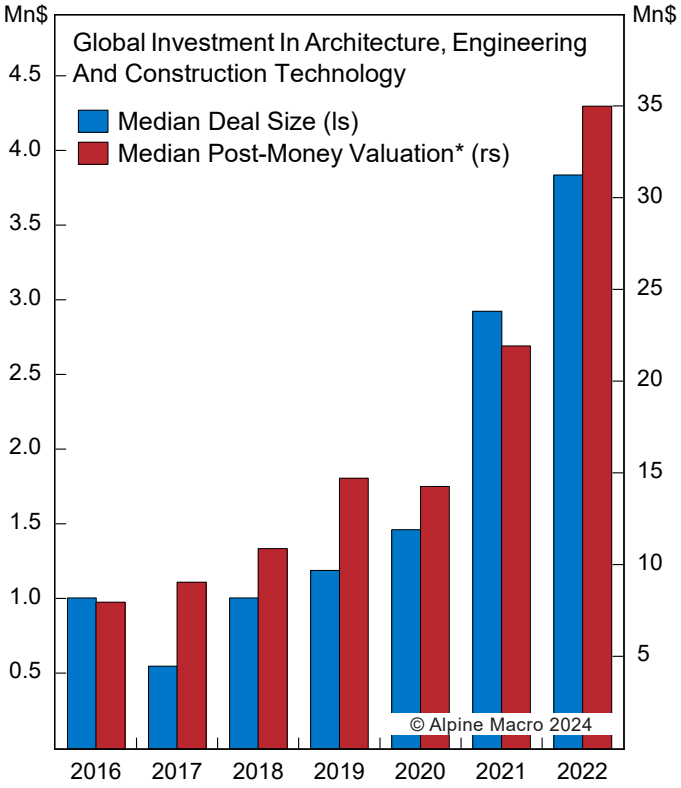
Promise Robotics believes their approach could construct a single-family home in about six hours or a 64-unit, three-story apartment building in just two weeks – 70% faster than traditional methods. The company is opening its first robotic production line this year and plans to deploy turnkey factories by 2025.

Chart 7 VC Funding Supporting Innovation



Note: Total funding excludes Katerra; source: Tracxn

Chart 8 Rapid Growth In AEC Tech Investment



*Where post-money valuation is a measure of a company's valuation including all external investments.
Source: PitchBook, McKinsey & Company

Investment Considerations

Although nebulous, we are in the camp that automation's impact on construction is on the precipice of a productivity enhancing boom. Importantly, technological innovation in the space continues to accelerate, largely being driven by advancements in AI, robotics, and drones. Hardware advancements that facilitate the extreme precision and accuracy of autonomous systems are key enablers. In addition, VC funding into construction technology continues to be robust, nearly increasing by 30x over the last decade (**Charts 7** and **8**).

As adoption costs fall and the ease of integration increases, firms in the construction sector that embrace automation's disruptive potential are set to outperform. We believe investors looking to capitalize on the upcoming productivity surge in construction should target companies developing solutions that integrate AI with physical infrastructure and automation. Examples include Trimble (TRMB), ABB (ABBN), and Samsara (IOT).

Noah Ramos
Global Strategist