From Bricks to Clicks: Mapping the White Space in Building Innovation

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ABSTRACT

It is a critical national imperative to transform the buildings sector, yet innovation is impeded by deployment failures that leave promising technologies stranded. Conventional market reports and techno-economic analysis provide an insufficient understanding of markets and resource allocation for emerging building technologies. They omit crucial commercialization factors such as market maturity and adoption friction, where the coordinated participation of a network of suppliers, contractors, financiers, regulators, and integrators is required to scale solutions. This study addresses these gaps by introducing an evaluation framework grounded in front-line data from six years of the DOE's IMPEL incubator, comprising experience from 300 building-sector innovators and the adjacent, complex network. Our methodology synthesizes top-down market analysis with bottom-up, practitioner-level data across five megatrends: (M1) Affordable materials and industrialized construction; (M2) Healthy and efficient mechanical systems; (M3) Intelligent building operations; (M4) Buildings as grid assets; and (M5) High-density power and cooling for data centers and therein identify twelve "white space" technology opportunities. Next, we develop a multi-criteria scoring rubric to rank these opportunities based on parameters, i.e., Affordability, Quality of Life, Reliability, and Security, yielding composite 'Demand' and 'Maturity' indices. Our results indicate that the most significant white spaces may not be incremental products but a new class of 'Market Enablers', such as logistics platforms, orchestration layers, and automated compliance software that solve structural deployment gaps. This paper summarizes this transparent, evidence-based, practitioner-informed evaluation framework for policymakers and investors to re-evaluate policy and resource allocation and unlock scalable market transformation.

Introduction

The U.S. building and construction industry is at an inflection point: faster construction is needed to address affordable housing, rapidly changing environmental patterns, a resurgent demand for domestic manufacturing infrastructure, and the explosive energy demands of digital infrastructure. Yet the industry remains structurally misaligned with the world it must serve, suffering from underinvestment in innovation, stagnant productivity, labor shortages, fragmented trades, and slow bureaucratic permitting processes. In this study, we map that white space for building innovation by analyzing the convergence of megatrends reshaping the construction and operation of buildings, and by identifying focused opportunities to transform this industry.

The stakes are substantial: the building market was valued at \$1.3T in 2024 and is projected to reach \$2.5T by 2030, with the building energy technology segment growing at nearly double that rate (Grand View Research 2024a). Yet, disinvestment and fragmentation continue to impede meaningful transformation. The industry faces a persistent innovation challenge: some technologies compete for the resources needed to move from R&D to large-scale adoption, while others that are technically mature fail to gain traction due to product–market misalignment in a fragmented network. Distinguishing signal from noise is difficult, since beyond high-level venture due diligence or alignment with a grantor's favorite priorities, no unbiased, systematic market-fit framework exists to prioritize which technologies merit advancement and resource allocation toward effective, industry-wide transformation.

This evaluation gap compounds a deeper resource allocation problem. Policymakers often lack evidence-based guidance on where incentives will prove most effective, while investor decisions are frequently shaped by momentum or hype within segments. According to Sightline, funding for energy and built-environment technologies rose 23% in 2025, but most of this capital flowed toward data center expansion rather than physical building-product innovation (Zou, Attwood, and Secon 2026). Physical building-product firms, from windows and insulation to industrialized construction robotics, require long-horizon, value-based investment that hype-driven capital bypasses, leaving high-potential technologies stranded. Conventional techno-economic assessment (TEA), while useful to identify cost drivers, does not capture commercialization factors, such as market maturity, adoption barriers, and deployment challenges, that ultimately determine market success.

Research Gap and Contribution

Collaborators in building-sector innovation consistently identify the absence of a commercialization-oriented assessment layer as a barrier to directing capital and partnerships toward high-potential opportunities or "white spaces". This paper addresses that gap directly, drawing on six years of front-line data from IMPEL, a DOE-funded building technologies incubator implemented by Lawrence Berkeley National Laboratory, which has supported nearly 300 building-sector innovators and engaged a network of 25 mentors. IMPEL's portfolio spans equipment and materials technologies to business-model innovations in software and services, including retrofit concierge services, data-integration platforms, and procurement, contractor-workflow, and financing solutions. This dataset enables three distinct contributions:

- Gap-linked opportunity identification: Integrating top-down megatrends with bottom-up IMPEL data connects market signals to overlooked white-space opportunities, yielding a shortlist grounded in both systemic demand and observed innovation activity.
- A commercialization ranking framework. A diverse range of opportunities ranked by market-readiness factors, moving beyond technical merit.
- A practitioner-oriented synthesis. Designed for decision support, rather than an academic exercise that can catalyze investment and partnership activity in the building sector.

Together, these contributions position the work as a methodological bridge between innovation-pipeline analysis and market-deployment strategy, a gap that neither traditional TEA nor conventional market reports have adequately addressed.

Methodology

This study takes a structured, evidence-based approach to identifying white-space opportunities in the buildings and energy technology sector. The process has three steps.

Step 1: Market landscape and opportunity identification

We conduct a structured literature review of current market trends to identify white-space opportunities in the buildings and energy technology sector. This review draws on national laboratory research, industry and institutional reports, published adoption and investment data, and technology roadmaps to characterize the current state of each megatrend: what is growing, what is stalling, and where capital is flowing. These top-down market signals are triangulated with bottom-up analysis from the IMPEL program (startups and collaborating expert mentors), whose six years of engagement with building-sector innovators provide practitioner-level visibility into deployment realities that published literature does not capture. Together, these sources are used to identify market gaps, cases where current solutions fail to meet real market needs at scale. We identify a white-space opportunity where a documented growth signal coincides with a persistent deployment gap. This process yields twelve specific technology opportunities across five megatrends.

Step 2: Multi-criteria opportunity scoring

Each of the twelve opportunities is scored on four criteria, based on a series of expert interviews with researchers and IMPEL mentors: Affordability (A), Quality of Life (QoL), Reliability (R), and Security (S), each rated on a scale from 1 (low) to 5 (high). 'Affordability' assesses cost-effectiveness, including a product's first, installation, and integration costs of current technology options/incumbents, as well as the impact of incentives and compliance costs. Quality of Life' indicates improvements to ease of use, health and comfort of users, consumer choice, and broader social/environmental outcomes. 'Reliability' indicates consistency of performance and uptime in real conditions, including compliance with required measurement and verification and regulatory standards, durability, and return on investment (ROI) over time. 'Security' measures how well the technology mitigates cyber-physical and supply chain risks.

These criteria are combined into two composite indices. The Market Demand Index (D) measures how strong and urgent the market pull is for each opportunity. Based on expert interviews, Affordability (A) has a slightly higher weight (0.60) because first cost, operating cost, financial incentives and penalty risks are the main drivers of short-term demand. Quality of Life (QoL) carries a slightly lower weight (0.40) but ensures that occupant impact is included, preventing the framework from favoring only low-complexity opportunities over higher-impact QOL providing ones in more challenging markets.

$$D = (0.60 \times A) + (0.40 \times QoL)$$

The Technology Maturity Index (M) measures technology viability and market readiness for commercial deployment. Based on expert interviews, Reliability (R) has a higher weight (0.60) because ease of installation, integration, and use, and proven field performance are the most important signs of technology maturity. Security (S) is weighted at 0.40 because factors such as cyber-physical security standards and supply chain strength are key components of market readiness and influence whether a technology can be scaled reliably.

$$M = (0.60 \times R) + (0.40 \times S)$$

Step 3: White space identification

White-space opportunities are technology areas where market demand is high, but technology maturity is still developing – the market need is clear, but it has not yet delivered a solution capable of meeting it at scale. Each opportunity is plotted on a demand-maturity chart, with D on the horizontal axis and M on the vertical axis. Because demand scores cluster narrowly across all twelve opportunities, Maturity emerges as the primary axis of differentiation, resolving the set into three clusters. Opportunities with $M \leq 2.5$ represent the clearest white spaces, where strong demand meets an underdeveloped market or technology infrastructure. Those with M between 2.5 and 4 indicate near-term investment readiness, suited to targeted techno-economic analysis and field demonstration. Opportunities with $M \geq 4.0$ are investment-ready and suited for scaled deployment. This clustering directly informs portfolio strategy: low-maturity opportunities need R&D and market development; moderate-maturity opportunities need financing and go-to-market support; high-maturity opportunities are ready to scale now.

Literature review of the current market landscape

This section synthesizes market-landscape research spanning megatrends, market needs, growth signals, and emerging gaps, drawing on publicly available sources and six years of front-line innovation intelligence from IMPEL (impel.lbl.gov). IMPEL has supported nearly 300 building and energy technology innovators whose collective outcomes include over $250 Million in follow-on funding, seven new manufacturing facilities, and 30+ commercial product launches, generating practitioner-level insight into what is working, where capital is flowing, and where the most significant market gaps remain. The real-world experience of these startups, and the 25 expert mentors serving the program informs this report and grounds the analysis in commercial reality rather than theory alone. Evidence-based findings are organized around five megatrends (M1 through M5), consolidated into a structured opportunity identification table.

Megatrend Synthesis

M1: Affordable building materials, industrialized construction, and speedier building workflows

Market Signals: On the material side, domestic cement costs are soaring, nearly $160/ton, up 30% in five years, driven by resource constraints, energy-intensive manufacturing, and consumption growth. The U.S. imports 25% of its cement, making it the world's largest cement importer (Concrete Financial Insights 2025). The massive 4 billion metric tons annual global cement demand, valued at over $300 billion, represents a major market opportunity for novel, validated cements and concrete (Gordian 2026). These signals are compounded by labor constraints, with 92% of construction firms reporting difficulty hiring and 45% reporting delays driven by shortages; this increases the value of approaches that reduce on-site labor intensity. These tailwinds are reinforced by severe labor constraints: 92% of construction firms report difficulty hiring skilled workers, and 45% cite labor shortages as a direct cause of project delays. Moreover, the U.S. construction sector faces a productivity crisis. The output per worker has remained largely flat for five decades, driven by fragmented trade structures, labor shortages, and regulatory friction that slows project delivery at every stage (McKinsey and Company 2017). The consequences are structural: housing is unaffordable, infrastructure is delayed, and the industry is misaligned with the scale and speed of demand it must serve. By contrast, projects using modular approaches can be completed 20–50% faster than conventional methods and can cut construction costs by about 20% (Bertram et al. 2019). On the delivery side, the U.S. modular construction market reached $20.3B in 2024, and the broader off-site market is projected to exceed $90B by 2031 (MBI n.d.).

Deployment Gaps: The alternative cement market is growing, from $2.75B in 2024 to a projected $6.21B by 2032 but remains a fraction of total cement demand. This is not a demand failure but a deployment failure (Aday et al. 2024; CRE 2025). Adoption of alternative cement assemblies is constrained by the lack of repeatable specifications and accepted performance equivalencies; without code-ready specifications, vetted supply chains, and standardized procurement pathways, even well-proven alternatives cannot be confidently specified at scale. Capital flows have similarly concentrated at the component level, factories, modular producers, and materials suppliers, while the logistical and coordination infrastructure connecting factory output to finished buildings remains systematically underfunded. Regulatory complexity compounds these gaps: permitting systems are highly heterogeneous across jurisdictions, building types, and occupancies, making standardization difficult, and the specialized AI expertise required to navigate them makes automated compliance software a technically demanding and relatively uncrowded space.

Investment Gaps: The gaps lie in the less glamorous, but equally critical, connective tissue that enables integration of the system. The investment in materials is focused narrowly on steel and cement (e.g., Brimstone, CarbonCure), and there is a significant lack of investment in scaling up cost-effective alternatives for other essential building components, such as high-performance insulation (e.g., wood fiber, cellulose, mycelium), and drywall alternatives to gypsum (e.g., bio-based or recycled wall panels). Second, while VC checks in automated factory production had been significant in companies like Katerra, Mighty Buildings and Modulus, they failed due to a combination of capital-intensive physical scaling needs, sluggish regulatory approvals, and a mismatch between factory overhead. There has been a major lack of investment in the logistics and on-site assembly layer in technologies for ultra-precise site layout (robotics), specialized crane and transport systems for modules, and software platforms that coordinate factory production schedules with on-site preparation. Moreover, while Clariti, OpenGov, Symbium, and others have raised venture capital to build cloud-based permitting platforms, there remains underinvestment in code-compliance AI tools that can address local code heterogeneity.

Insights from IMPEL: The 90+ IMPEL startups in this area fall under three primary categories, as follows. (1) Next-generation essential building materials & components, i.e., startups creating direct replacements for high-energy-intensity materials like cement, steel, insulation, and toxic binders; or designing entirely new building blocks. For instance, Klaw Industries has a patented process for creating high-quality cement replacement from recycled glass waste; Thermagel has developed R14-R35 fire-rated 1-inch-thick aerogel insulation; Inventwood has begun manufacturing cellulose-based building products as an alternative to steel. (2) Industrialized construction & advanced manufacturing startups such as Assembly OSM and Forma systems are leveraging AI and robotics, dematerialized cement structural components, and prefabrication, while others like KitSwitch are creating modular interiors to rapidly convert vacant buildings into apartments. (3) AI-powered platforms: Startups such as ProspexGeo automate and streamline the complex, time-consuming workflows in land acquisition; Design and code compliance platforms such as Ulama; and utility rebates streamlining platforms such as Rock Rabbit have gained funding and early adoption.

M2: Mechanical systems at the convergence of Affordability, Efficiency and Human Health

Market signals: The post-pandemic-built environment is not just a backdrop to daily life; it is an active determinant of human health. Rising energy costs, intensifying weather extremes, and the mounting evidence linking indoor air quality to cognitive performance and chronic disease have converged into an unavoidable reckoning on mechanical and natural thermal and ventilation systems. Stricter building energy codes and performance standards, and state and municipal electrification mandates are converging to create a massive market for high-efficiency Heating, Ventilation, Air Conditioning, and Refrigeration (HVACR) and Domestic Hot Water (DHW) systems. Heat pump sales in the U.S. suggest continued growth at an estimated 8–9% CAGR through the early 2030s, with significant momentum in larger systems for multifamily and light commercial applications (Mordor Intelligence n.d.).Electric water heaters now account for approximately 54% of sales (R.M.I. 2026). The North American dehumidifier market is projected to grow at a CAGR of 7.3%. The combined addressable market opportunity is $100B+ globally and growing at a combined CAGR of 9-11% (Grand View Research 2024b).

Deployment Gaps: These extend beyond improvements in equipment efficiency alone. Standardized, integrated equipment packages remain unavailable for multifamily and light-commercial contexts at accessible price points. Cold-climate heating performance continues to constrain electrification in the northern markets, where field performance data is the primary procurement driver for property owners and utilities. Across all three sub-segments, business solutions, including commissioning workflows, accessible financing, and a coordinated installation workforce, are as absent as the hardware gaps themselves.

Investment gaps: Venture capital is backing scalable, tech-first businesses to solve for consumer friction and high upfront costs, such as Quilt, Dandelion, and Harvest. Jetson secured a $50 million Series A round in 2026 to simplify adoption of its heat pump system, to aiming of reduce installation costs by 30-50% compared to competitors (Takemura 2026).

Insights from IMPEL: A portfolio of 20 IMPEL startups are focusing on (i) Next-generation heat pumps and thermal systems that are efficient, affordable, and practical for a wider range of buildings; (ii) Beyond-filtration products that actively manage and improve indoor air quality (IAQ) by targeting pathogens and CO2; and (iii) Thermal innovation focused on capturing and reusing energy that is already being produced within a building. For instance, IMPEL startup Aris utilizes an efficient air-to-water hydronic system to provide integrated heating, cooling, and hot water and matches the installation cost of legacy systems for the underserviced multifamily sector through a vertically integrated business model. Genesys utilizes a novel closed-loop advection device for efficient geothermal heating and cooling.

M3: Intelligent building operations and maintenance

Market signals: The digital opportunity is driven by both low market penetration and demonstrated potential for energy savings. ~13% of U.S. commercial buildings report having building automation systems (BAS) for any end use; but penetration is concentrated in large buildings, with a significant gap in the small- and medium-building (SMB) segment (Trenbath et al. 2002). Case studies report energy savings of 20–25% and demand flexibility of 10–20% using solutions assembled from off-the-shelf components, suggesting substantial near-term value if deployment can be standardized (Katipamula et al. 2024). For energy management and information systems (EMIS), best-practice implementations report portfolio savings of 11–22%, FDD implementations report 15–28%, and automated system optimization (ASO) deployments report 5–11% whole-building savings (Goetzler et al. 2024). Participation in the DOE's Better Buildings initiative and increased procurement activity further indicate progress toward expanded EMIS adoption across large-building portfolios (Building Efficiency Targeting Tool for Energy Retrofits 2026).

Deployment gaps: Despite proven performance, scaling intelligent building operations faces three persistent barriers. First, data fragmentation across incompatible systems and protocols forces custom engineering on every project, making integration cost the dominant deployment barrier. Second, high deployment complexity prices out SMB owners who lack the technical staff to manage procurement and commissioning. Third, AI-driven control systems whose outputs are difficult to validate, audit, or procure against standard cybersecurity requirements remain commercially inaccessible to most building owners, even those with demonstrated interest in performance optimization.

Investment gaps: Major investments have happened in this space in the past 3-5 years, again focused on sophisticated solutions for large buildings. Examples include AI software startups that autonomously optimize building systems such as Turntide, and BrainBox AI with its predictive HVAC control platform. Industrial giants have acquired technologies: Google bought

IAQ-monitoring company Awair, Siemens acquired digital twin software providers, and Schneider acquired Foghorn edge AI system to integrate intelligence into their own smart building platforms. Operational digital twin companies such as Willow and Matterport have also raised large amounts of capital.

Insights from IMPEL: An analysis of 26 IMPEL portfolio startups shows two key foci. (i) AI-driven control & optimization in SMBs. Monaire uses AI-based automation to reduce energy bills and repair and maintenance costs for small retail facilities. (ii) Data platforms, remote audits, and analytics tools. Zero Homes enables homeowners to create a digital twin of their home using a video scan, photos, and utility data, and to deliver energy equipment upgrades from local contractors. Enamp provides remote audits using computer vision for SMBs.

M4: Buildings as grid assets: Flexible loads and hybrid storage

Market signals: Buildings can serve as active grid participants through behind-the-meter energy storage and grid-interactive controls that optimize energy use in response to dynamic tariffs and grid conditions. The policy and investment case is strong: aggregated load control strategies are expected to generate up to $200 billion in cumulative energy cost savings by 2040, driving demand for software solutions to operationalize these strategies (Satchwell et al. 2021). Building-scale storage systems and coordinated controls are increasingly prioritized in federal and state policy roadmaps. Research further indicates that envelope and HVAC improvements can significantly reduce coincident effective peak loads, reinforcing the combined value proposition of efficiency and storage (Pritoni et al. 2024).

Deployment gaps: Integrated solutions combining appropriately sized storage with efficiency-aware design, tariff-aware co-optimization, and interoperability across diverse BAS and generation-hybrid storage platforms remain scarce. The dominant gap is not hardware availability but the absence of software and control layers that can deliver reliable, validated performance across building portfolios and utility markets. Utility interconnection complexity and the absence of standardized demand-response protocols present scaling barriers that are more constraining than either hardware cost or software capability.

Investment Gaps: On the hardware side, investments are required in holistic solutions that include deep energy retrofits and properly sized, reliable multi-hour storage systems, financed through long-term service agreements needed to make storage-plus-controls viable outside the most subsidized markets. Investment that avoids the hype and is done with due diligence in the next-generation, AI, and digital twin platforms that have transparency and accountability and can perform co-optimization across loads and edge energy systems with the right level of data integration, control maturity, and time resolution

Insights from IMPEL: 30+ IMPEL teams are creating the key physical assets and the intelligent software needed to transform buildings from passive loads into active, flexible participants in the electric grid. Energy storage companies focused on the physical atoms of flexible buildings also employ integrated AI/software to manage assets. Pila Energy has a low-cost battery platform that turns appliances like refrigerators into a backup power hub, and MicroEra Power optimizes its thermal battery for grid services. Communications & controls startups primarily focus on the bits, i.e., they are purely software plays, using AI and analytics to control and optimize adjacent hardware assets for grid interaction. For instance, Curve Control and Pace AI optimize and manage distributed loads, and Edo and ecoLong aggregate demand, storage, and generation flexibility, respectively, acting as the orchestrator between buildings and the grid for commercial and residential applications.

M5: Powering and Cooling High-density Data Centers

Market signals: AI data centers face two interrelated constraints: high site power density and extreme rack heat flux. Nearly all electricity used for computation is converted into heat that is wasted. Even with improved power usage effectiveness (PUE > 1), ~30% of total electricity is consumed by non-computational loads, primarily for cooling. High-density racks are becoming standard in hyperscale facilities, making liquid cooling a baseline rather than an optional efficiency improvement. Liquid-cooling technologies' revenues are projected to reach ~$2B by 2027, with North America as a primary demand center (Dell'Oro Group 2023). U.S. data centers may account for 8–12% of total national electricity use by 2030 (Denman et al. 2025), with estimated consumption rising to 325–580 TWh by 2028 (Shehabi et al. 2024).

Deployment gaps: Power and cooling are still treated as separate design challenges in most facilities, creating integration inefficiencies and extending time-to-power for new capacity. On the cooling side, retrofit-compatible liquid and hybrid cooling systems that are water-efficient and easy to service are available, but lack standardized deployment packages that integrate thermal and power management into a single procurable solution. Waste heat recovery represents a large but stranded opportunity: approximately 70–80% of generated heat is theoretically recoverable. Although advances in AI-driven hardware and liquid cooling are increasing heat quality (often exceeding 50°C), no standardized datasets, system frameworks, or decision- support methodologies exist to evaluate viable recovery pathways across cooling technologies and end uses, resulting in this resource being consistently dissipated rather than monetized.

Investment Gaps: This is one of the hottest areas of investment, with ambitious projections around how AI companies will power their data centers: on-grid, off-grid, on-edge, or even off-planet. Next-generation power distribution units (PDUs) are being provided by incumbents such as Eaton, Schneider, and Legrand, delivering over 100kW to a single rack using new overhead modular busbar systems. Hyperscalers are bringing their own power capacity to address the grid interconnection queues. On the thermal side, direct-to-chip liquid cooling is being pursued by major players such as Vertiv and Schneider, as well as venture-backed companies like JetCool and ZutaCore. Companies like LiquidStack and Submer have raised capital to scale immersion cooling solutions with hyperscalers and supercomputing partners. However, there are gaps in AI-powered digital twins for planning, grid integration & orchestration, and cost-effective last-mile heat reuse.

Insights from IMPEL: A handful of teams have pivoted to data center applications, such as next-generation CHP systems that deliver power, heat, cooling, and water with high efficiency and multi-fuel capabilities. Florrent is a biowaste-based supercapacitor solution that provides fast backup power and enables data center peak shaving.

Results

Opportunity Identification

The assessment and synthesis across M1–M5 yields twelve candidate near-term opportunities, each anchored in documented market signals and corresponding deployment gaps.

M1. Affordable building materials, industrialized construction, and speedier building workflows: (M1.1) Logistics and assembly platform for industrialized construction, encompassing digital twins, robotics, on-site assembly, commissioning, and repeatable off-site retrofit modules for deep performance with minimal occupant disruption. (M1.2) Building products procurement marketplace with vetted products, code-ready specification tools, and streamlined procurement and financing to ensure low-cost options and robust supply chains. (M1.3) Automated design compliance and construction permitting software for heterogeneous regulations across jurisdictions, a technically demanding and less crowded space than general workflow software.

M2. Mechanical systems at the convergence of affordability and health: (M2.1) Integrated HVAC packages with thermal storage and alternate refrigerants for multifamily and light-commercial contexts. (M2.2) Dehumidification and ventilation equipment for high-humidity conditions. (M2.3) High-performance cold-climate heating equipment as retrofit-ready replacements for legacy systems. Business solutions, i.e. commissioning workflows, accessible financing, and coordinated installation for all of the above.

M3. Intelligent building operations and maintenance: (M3.1) Unified building energy data orchestration platform using open architectures, semantic standards, and modern APIs (e.g., Haystack, Brick) to reduce integration costs. (M3.2) Plug-and-play building automation systems with low-touch installation and commissioning for strong ROI. (M3.3) Autonomous building controls with integrated EMIS, FDD, and ASO through auditable AI workflows and cybersecurity-ready procurement artifacts.

M4. Buildings as grid assets, flexible loads and hybrid storage: (M4.1) Grid-interactive load-flexible building system with hybrid energy storage, combining appropriately sized storage with efficiency-aware design and tariff-aware co-optimization, delivered through interoperable AI and digital twin layers that scale from individual buildings to entire portfolios.

M5. Powering and cooling high-density data centers: (M5.1) Efficient data center powering and cooling packages that scale from 100 kW to MWs per rack while managing water and reliability, pairing retrofit-compatible liquid or hybrid cooling with power architectures that reduce interconnection risk through on-site backup, storage, and grid-services integration. (M5.2) Edge data centers, decentralized facilities located within residential and smaller commercial environments. This opportunity is driven by grid interconnection constraints, power tariff structures, and latent electrical capacity at distributed sites, enabling lower latency and potential waste-heat reuse for co-located district heating, agriculture, and industrial applications.

Multi-criteria scoring and White Space analysis

The twelve opportunities identified are rated on four criteria: Affordability (A), Quality of Life (QoL), Reliability (R), and Security (S), on a scale from 1 (low) to 5 (high), using current technology availability to ensure consistency and traceability. These four criteria are combined into two composite indices as described in the Methodology section. The Market Demand Index (D) weights Affordability at 0.60 and Quality of Life at 0.40. The Technology Maturity Index (M) weights Reliability at 0.60 and Security at 0.40, per expert opinion.

Demand-Maturity Results and Ranking

Table 1 presents scoring results for the twelve opportunities. Demand scores range narrowly from 3.2 to 4.2, underscoring that all identified opportunities represent strong market need. Maturity scores show considerably wider variation, from 2.0 to 4.0, reiterating that the capacity to serve existing demand, not the demand itself, is the primary differentiating factor.

Table 1: Scoring results for the twelve opportunities.

Opportunity	Affordability (A)	Quality-of-life (QoL)	Reliability (R)	Security (S)	Demand (D)	Maturity (M)
M1.1 Logistics & assembly platform for industrialized construction	2	4	4	3	3.2	3.6
M1.2 Building products procurement marketplace	4	4	4	2	4	3.2
M1.3 Automated design compliance and construction permitting software	4	4	2	2	4	2
M2.1 Integrated HVAC packages with thermal storage and alternate refrigerants	3	5	4	4	4.2	4
M2.2 Dehumidification and ventilation equipment	3	5	3	4	4.2	3.4
M2.3 High-performance cold-climate heating equipment	2	5	3	4	3.8	3.4
M3.1 Unified building energy data orchestration platforms	3	4	3	3	3.6	3
M3.2 Plug-and-play building automation systems	4	4	3	4	4	3.4
M3.3 Autonomous building controls with integrated EMIS, FDD, and ASO	2	4	2	2	3.2	2
M4.1 Grid-interactive load flexible building system with hybrid energy storage	2	4	4	3	3.2	3.6
M5.1 Efficient data center powering and cooling packages	3	4	4	4	3.6	4
M5.2 Edge data centers	4	4	2	2	4	2

Affordability scores range from 2 to 4. Four opportunities: M1.2, M1.3, M3.2, and M5.2 score 4, reflecting strong ROI driven by compliance incentives or clear payback pathways. M1.1, M3.3, M2.3, and M4.1 score 2, reflecting high upfront costs or uncertain payback. Where affordability is low, demand scores are constrained regardless of technical merit.

Quality of Life scores are uniformly high: nine opportunities score 4 and three score 5. M2 achieves the highest QoL scores, underscoring that improvements in thermal comfort, IAQ, consumer choice and energy bills reduction creates stable demand, independent of incentives.

Reliability scores range from 2 to 4. Hardware technologies M2.1, M4.1, and M5.1 score 4, reflecting mature field deployment. AI solutions M1.3, M3.3, and M5.2 score 2, reflecting inconsistent real-world validation and non-interpretable decision-making.

Security follows a similar pattern: technologies with clear compliance frameworks score 4, while AI solutions score 2, reflecting relative mistrust in the cybersecurity exposure, and the absence of building-sector-specific standards.

White-space characterization

Figure 1 maps the twelve opportunities on the demand-maturity plane, reveals three distinct clusters, and represents a coherent portfolio strategy for policymakers and investors.

Three opportunities sit in the high-demand, low-maturity region that represents the clearest white spaces requiring R&D funding and market development to close the maturity gap. M1.3 Automated construction compliance and permitting software (D=4.0, M=2.0) exhibits the largest demand-maturity gap in the set. M5.2 Edge data centers (D=4.0, M=2.0) shares this position, reflecting strong market pull against significant infrastructure and regulatory immaturity. M3.3 Autonomous building controls with integrated EMIS, FDD, and ASO (D=3.2, M=2.0) represent an emerging white space where its low maturity signals both the difficulty of the problem and the leverage available to whoever solves it first.

The majority of opportunities cluster in the high-demand, moderate-maturity region, indicating near-term investment readiness. These require innovation in financing, go-to-market support, and standardization. M1.2 Procurement marketplace (D=4.0, M=3.2), M2.2 Dehumidification and ventilation equipment (D=4.2, M=3.4), M3.2 Plug-and-play BAS (D=4.0, M=3.4), M3.1 Orchestrator data platform (D=3.6, M=3.0), and M1.1 Logistics and assembly platform (D=3.2, M=3.6) are approaching commercial viability and are well-positioned for targeted techno-economic analysis and field demonstration.

At the high-demand, high-maturity end of the plane, M2.1 Integrated HVAC packages (D=4.2, M=4.0) and M5.1 Efficient data center powering and cooling packages (D=3.6, M=4.0) are investment-ready and suited for scaled deployment rather than further development.

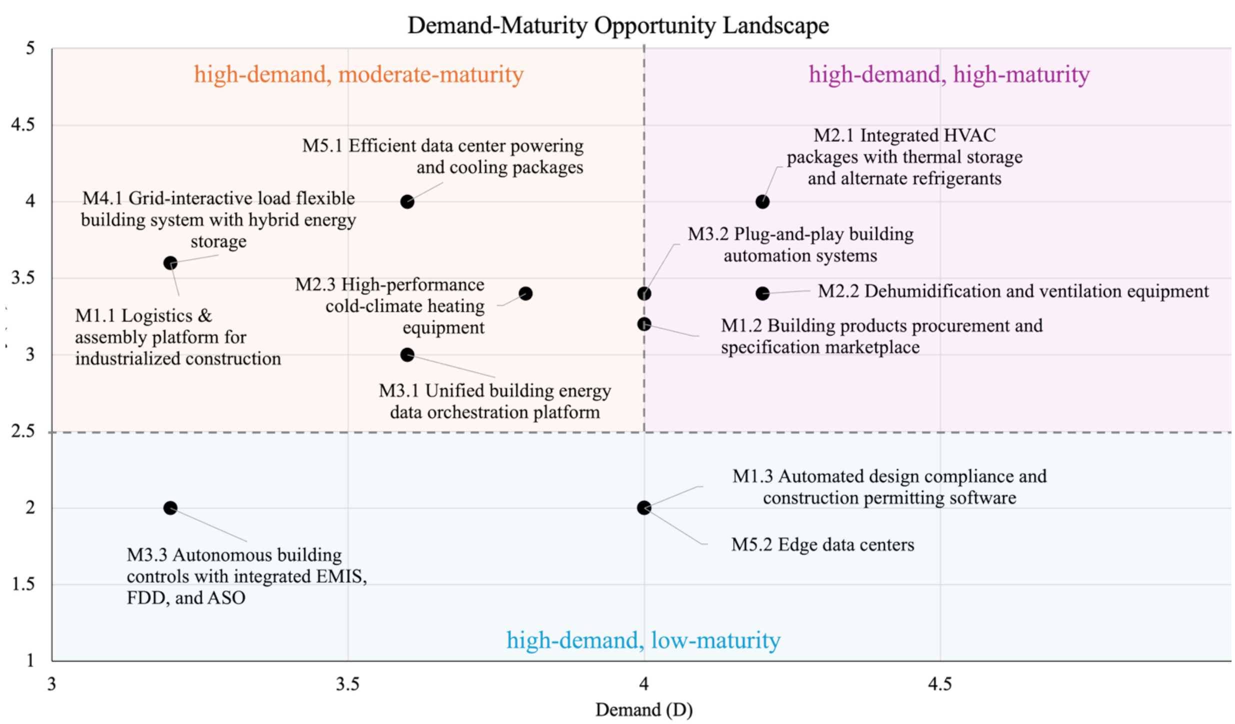

Figure 1: Plot of the twelve opportunities on the demand-maturity plane

Discussion

Demand is high, but Maturity divides the opportunity set

The results show a narrow range of Demand scores (3.2 to 4.2) since these 12 opportunities are built using demand signals, but a much wider range of Maturity scores (2.0 to 4.0). This indicates that while regulation and end-user needs have validated demand across all five megatrends, the ability to meet that demand varies significantly by technology. Lack of maturity to serve existing markets at scale is the main factor distinguishing white-space opportunities in the built environment. Interventions that improve market readiness, such as technical derisking, field demonstration, deployment playbooks, workforce training, and supply chain investment, are likely to unlock deployment more effectively than those focused solely on generating demand through compliance mandates or policy levers.

Affordability as a primary bottleneck for emerging opportunities

The four opportunities with Demand scores of 3.2, i.e. Logistics and assembly platform, Autonomous controls, Load flexibility, and Orchestrator platform, all have an Affordability score of 2 in current technologies, indicating uncertain payback that relies on incentives and customization. This 'affordability gap' highlights a market failure where technically sound solutions lack the standardization and financing structure needed for mainstream adoption. In contrast, M1.3 Automated compliance software and M3.2 Plug-and-play BAS, both with Affordability scores of 4, show that clear deployment pathways significantly increase Demand. For lower-scoring opportunities, advancing to primary white-space status depends more on financing innovation and go-to-market strategy than on further technology development.

Quality of life as a commercial driver

Consistently high QoL scores across all twelve opportunities, with nine scoring 4 and three scoring 5, demonstrate that building technologies can provide meaningful, visible benefits to occupants. Strong QoL can function as a stable baseline, creating demand that persists despite changes in incentives or financing conditions. The three M2 opportunities achieve the highest Demand scores partly due to their QoL scores of 5, reflecting direct improvements in indoor air quality, occupant comfort, consumer choice, and reduced energy bills, which amplify even moderate Affordability scores. Solutions that make occupant outcomes visible and measurable are better positioned to sustain demand regardless of policy changes.

AI dependency as a Maturity risk

Two opportunities from different megatrends share the lowest Maturity score of 2.0: M3.3 Autonomous control integrated with EMIS, FDD, and ASOs, and M1.3 Automated compliance and construction permitting software. Both are increasingly AI-dependent, leading to shared risks, including non-interpretable decision-making, inconsistent real-world validation, and cybersecurity vulnerabilities. As AI becomes more integrated into intelligent building operations, including Orchestrator platforms, advanced EMIS applications, and grid-interactive control systems, the same reliability and security challenges risk becoming sector-wide barriers to maturity. Establishing AI transparency standards, M&V compliance frameworks for AI-driven systems, and building-sector-specific cybersecurity protocols are immediate priorities for standards bodies, regulators, and investors.

The real white space: Market enablers, not incremental products

A key finding is not which opportunities score the highest, but rather what the score patterns reveal about the deployment gap in the buildings sector. There is a persistent divide: some technically viable innovations remain stranded at a small scale, while urgent market needs go unmet by viable solutions. The gap is primarily a market gap, not a technological one (Figure 2). The sector lacks the infrastructure to integrate proven components into deployable, financeable, and scalable solutions.

This highlights a class of high-value opportunity identified by the scoring framework but often overlooked by product-focused investors: Market Enablers. These market catalysts are platforms, integrators, and orchestration layers that bridge the deployment gap rather than merely adding another product to the fragmented market. M1.1 Logistics & assembly platform for industrialized construction is a clear example. While venture capital has funded factories, modular component producers, and advanced materials suppliers, it has underinvested in the link between factories and finished buildings. Similarly, M1.3 compliance and construction permitting software (D=4.0, M=2.0) and M3.1 Unified building energy data orchestration platforms (D=3.6, M=3.0) are infrastructure solutions that enable the network to function and overcome adoption friction. Without these enablers, even mature technologies remain stranded at the project level and cannot scale across portfolios, jurisdictions, or building types.

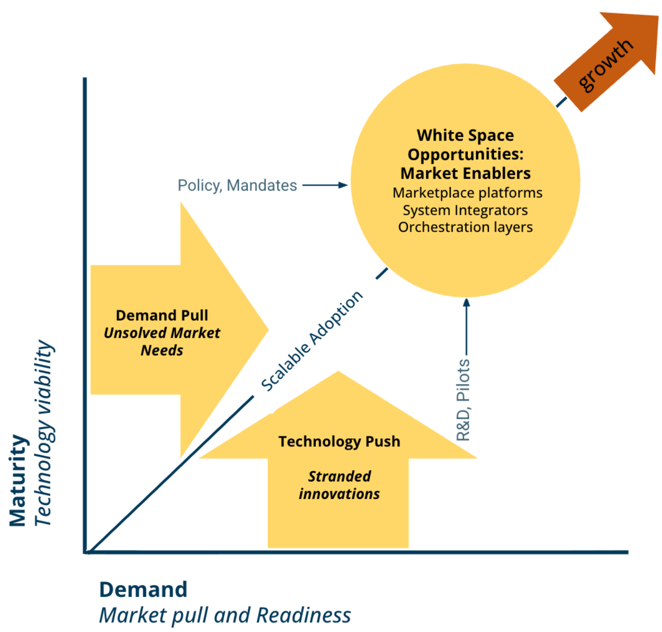

Figure 2: Schematic showing white space opportunities where demand meets mature technology.

Conclusion

This study developed and applied a structured methodology to identify white-space technology opportunities in the built environment. By integrating market growth signals with observed gaps across five megatrends and evaluating each opportunity on Affordability, Quality of Life, Reliability, and Security, the framework offers a transparent and reproducible way to pinpoint areas with strong demand, limited market readiness, and favorable conditions.

A central lesson of this analysis is that *just because there is a gap in the market doesn't mean there is a market in the gap*. An unmet need is necessary but not sufficient for a viable opportunity; what determines whether a gap can be commercialized is the maturity of the surrounding market and the conditions that allow a solution to be adopted, financed, and scaled. The framework's value lies precisely in distinguishing gaps that represent actual markets from those that remain structurally closed.

Three findings illustrate where this distinction matters most. First, the affordability gap emerges as a primary bottleneck, representing a market failure in which technically sound solutions lack the standardization and financing structures required for mainstream adoption. Second, quality of life functions as a durable commercial driver rather than a soft benefit: solutions that make occupant outcomes visible and measurable are best positioned to sustain demand regardless of policy change. Third, AI dependency introduces a systemic maturity risk.

This framing surfaces a class of high-value opportunities that the scoring framework identifies but that product-focused investors routinely overlook, the Market Enabler. These are the marketplace platforms, system integrators, and orchestration layers that bundle and bridge the deployment gap rather than adding yet another product to an already fragmented market. These can allow the broader market to function and overcome adoption friction. Without such enablers, even mature technologies remain stranded at the project level, unable to scale across building types, portfolios, or jurisdictions. This is where the highest-leverage opportunities exist, as consistently indicated by the framework, the gaps that, with the right enabling infrastructure and investments, can finally become markets.

Several limitations merit acknowledgment. The scoring criteria reflect our synthesis of market evidence, barriers observed among IMPEL innovators, and published industry and policy data, with weights informed by expert feedback rather than a formally optimized model. Because technologies operate within complex, context-dependent networks, the four criteria cannot capture all commercialization factors. For instance, regional policy variation and appetites for innovation, supply chain dynamics, and workforce availability will each bear differently on individual opportunities. The framework is therefore best understood not as a ranking instrument but as a structured, evidence-grounded approach to comparing technology opportunities, offering a consistent, traceable basis for prioritization that can be updated as markets evolve.

Capturing these opportunities also requires a distinct entrepreneurial strategy. Market enablers must be built from the ground up, focusing early on network formation rather than market capture. This shifts the operative model from the Minimum Viable Product (MVP) to what we term the Minimum Viable Network (MVN): the interconnected set of participants and relationships, viable network catalysts to generate real value within a market. Where the MVP validates a product, the MVN validates the connective tissue. This MVN must be formed between manufacturers, suppliers, contractors, financiers, and regulators. This demands a land-and-expand approach: begin with the smallest deployable network that delivers credible outcomes, then use each success as both proof of concept and the foundation for the next layer.

The buildings sector is being actively shaped by emerging founders, early-stage investors, and policymakers. We have identified the opportunities, mapped the gaps, and provided the analytical tool. The next phase is the challenging, creative work of building the integrators, platforms, and networks the sector needs, making this an exciting space to watch closely.

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References

Aday, A., K. Richardson, D. France, J. Olavarria, J. Schaidle, and T. Cozart. 2024. "State of Innovation 2024: Paving the Way for Low-Carbon Cement and Concrete (NREL/FS-6A65-90529." In *National Renewable Energy Laboratory*, https://docs.nlr.gov/docs/fy24osti/90529.pdf.

Bertram, N., S. Fuchs, J. Mischke, R. Palter, G. Strube, and J. Woetzel. 2019. *Modular Construction: From Projects to Products*. McKinsey & Company. https://www.modulargenius.com/wp-content/uploads/company-info/Architect-Web-Page-Resources/McKinsey-Report.pdf.

"Building Efficiency Targeting Tool for Energy Retrofits (BETTER." 2026. In *U.S. Department of Energy*, https://better.lbl.gov/.

"Concrete Financial Insights." 2025. https://concretefinancialinsights.com/us-cement-industry-data.

CRE, Mile High. 2025. "Embodied Carbon: BranchPattern Unveils 2024 Benchmark Findings." https://milehighcre.com/embodied-carbon-branchpattern-unveils-2024-benchmark-findings/.

Dell'Oro Group. 2023. "AI Workloads to Accelerate Data Center Physical Infrastructure Growth Trajectory." https://www.delloro.com/news/ai-workloads-to-accelerate-data-center-physical-infrastructure-growth-trajectory/.

Denman, A., M. Rouch, P. Hanbury, P. Brick, and T. Quinn. 2025. "Can the US Energy Grid Keep up with AI Data Centers?" In *Bain & Company*, https://www.bain.com/insights/can-the-us-energy-grid-keep-up-with-ai-data-centers-snap-chart/.

Goetzler, B., J. Young, M. Umland, M. Butrico, and C. Torrado. 2024. "Cool Refrigerant Developments for a Warming World: Low GWP HVAC Refrigerant Regulations and Technologies in US and Global Markets." In *Proceedings of the 2024 ACEEE Summer Study on Energy Efficiency in Buildings*, https://www.aceee.org/sites/default/files/proceedings/ssb24/pdfs/Cool%20Refrigerant%20Developments%20for%20a%20Warming%20World%20-%20Low%20GWP%20HVAC%20Refrigerant%20Regulations%20and%20Technologies%20in%20US%20and%20Global%20Markets.pdf.

Gordian. 2026. "What the Data Says: Concrete Cost Updates." https://www.gordian.com/resources/concrete-cost-updates/.

Grand View Research. 2024a. *Building Technologies Market Size, Share & Trends Analysis Report*. San Francisco, CA: Grand View Research. https://www.grandviewresearch.com/industry-analysis/building-technologies-market.

Grand View Research. 2024b. "North America Dehumidifier Market Size, Share & Trends Analysis Report by Product, by Application, by Technology, by Country, and Segment Forecasts." https://www.grandviewresearch.com/industry-analysis/north-america-dehumidifier-market-report.

Katipamula, S., R. Lutes, C. Goodman, W. Kim, M.G. Yu, and S. Huang. 2024. "Development and Validation of a Low-Cost Building Automation System for Small- and Medium-Size Commercial Buildings." In *Proceedings of the 2024 ACEEE Summer Study on Energy Efficiency in Buildings*, https://www.aceee.org/sites/default/files/proceedings/ssb24/pdfs/Development%20and%20Validation%20of%20a%20Low-Cost%20Building%20Automation%20System.pdf.

MBI (Modular Building Institute). n.d. Industry Analysis. Charlottesville, VA: MBI. www.modular.org/industry-analysis/.

McKinsey and Company. 2017. "Reinventing Construction Through a Productivity Revolution." *McKinsey Global Institute*. www.mckinsey.com/~/media/mckinsey/business%20functions/operations/our%20insights/reinventing-construction-a-route-to-higher-productivity-full-report.pdf.

Mordor Intelligence. "United States Heat Pump Market Size & Share Analysis." https://www.mordorintelligence.com/industry-reports/united-states-heat-pump-market.

Pritoni, M., M. Wetter, L. Paul, A. Prakash, W. Huang, and S. Bushby. 2024. "Digital and Interoperable: The Future of Building Automation Is on the Horizon. What's in It for Me? Lawrence Berkeley National Laboratory." *OSTI* ID: 2439969.

R.M.I. 2026. "Tracking the Heat Pump & Water Heater Market in the United States." https://rmi.org/resources/tracking-the-heat-pump-water-heater-market-in-the-united-states/.

Satchwell, A., M.A. Piette, S. Schiller, S. Murphy, J. Tang, R. Hledik, T. Chang, A. Lukachki, and D. Nemtzow. 2021. *A National Roadmap for Grid-Interactive Efficient Buildings*. Lawrence Berkeley National Laboratory; The Brattle Group; U.S. Department of Energy. doi:10.2172/1785535.

Shehabi, A., S.J. Smith, A. Hubbard, A. Newkirk, N. Lei, M.A.B. Siddik, B. Holecek, et al. 2024. https://eta-publications.lbl.gov/sites/default/files/2024-12/lbnl-2024-united-states-data-center-energy-usage-report_1.pdf.

Trenbath, Kim (ORCID:0000000167388327), Ryan (ORCID:0000000163173628) Meyer, Korbaga Woldekidan, Kristi Maisha, and Morgan Harris. 2002. *Commercial Building Sensors and Controls Systems: Barriers, Drivers, and Costs*. United States. https://www.osti.gov/biblio/1871297.

Zou, K., J. Attwood, and H. Secon. 2026. "Climate Tech Investment 2025: $40.5B in VC & Growth Trends." In *Sightline Climate*, https://www.sightlineclimate.com/research/40-5bn-and-8-uptick-as-power-demand-drives-25-investmentx.

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