

DESIGN FLEX 2030

ROADMAP FOR CHANGE:

THE FLEXIBLE INDUSTRIAL DISTRIBUTION FACILITIES NETWORK OF THE FUTURE

IAMC
INDUSTRIAL ASSET MANAGEMENT COUNCIL

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This paper is part of the DesignFlex2030 initiative, commissioned by IAMC and SIOR with funding from the SIOR Foundation, to explore new design approaches that could lead to more flexible, adaptable, and sustainable industrial facilities in the future. Other papers in this series include "Recipe for Change: The Flexible Food Processing Plant of the Future," published in September 2015, and "Rx for Change: The Flexible Biopharmaceutical Facility of the Future," published in March 2017.

As part of DesignFlex2030, initiated by the Industrial Asset Management Council (IAMC) and the Society of Industrial and Office Realtors (SIOR), with funding from the SIOR Foundation, a top-notch team of architects and engineers set out to explore and understand the massive changes in the distribution industry already underway. They aimed to design an industrial distribution network that has the flexibility to accommodate future change and the increasingly customer-centric direction in which businesses are going. The idea is grounded in reality but draws on an imaginative forecasting of the state of society, looking out 25–50 years. This paper details their work.

FOREWORD

Striking architectural design. Placemaking visual appeal. Smart floors. Hypervelocity loading docks. ASRS as performance art. Hybrid factory and warehouse. Underground freight tunnels. Autonomous freight carriers. Modularity. This is the vocabulary of a forward-looking distribution industry. They are concepts embedded in the innovative designs presented in this paper, "Roadmap for Change: The Flexible Industrial Distribution Facilities Network of the Future."

A creative rethinking of a more connected, productive, and flexible network of distribution facilities as disruptive trends permanently alter supply chains in the future, the designs presented here embody the core mission of the DesignFlex2030 initiative: to reimagine industrial facilities for longer term usefulness even amidst the waves of change sure to come.

From the outset, the team involved in developing this paper understood the challenge they faced: While every industry sector that produces goods must contend with these changes, no two supply and fulfillment chains are the same. By no means a single solution to the varied and complex distribution dilemmas faced by every industry, the paper instead offers innovative ideas and concepts that can serve as a jumping-off point for new approaches across the range of industries. It provides a window into a more flexible future.

We would like to acknowledge the creative brains behind this paper. We thank the author, Ann Moline, who has been with us since the very start of this initiative. We thank the gifted architects and engineers who shared their talents to imagine the designs: Karl Heitman and his team from Heitman Architects and Andrew Cannon and his team from Ghafari and Associates. Thanks also go to their companies, which allowed their key staff to dedicate countless hours to this project. Joel Parker, Director, Professional Education & Research for IAMC, has served as the DesignFlex 2030 Project Lead throughout the entire initiative, and we thank him.

We extend our gratitude to the IAMC and SIOR advisory group, including Ken Hagaman, Jennifer Lantz, and Corinne Nowak, for their help and guidance, as well as to IAMC active members who provided input and feedback. We also acknowledge the IAMC and SIOR boards of directors for their support. We thank our firms, Novartis and McKinney Capital & Advisory, for allowing us to devote so much time to this research initiative.

On a personal note, this represents the fourth white paper for which we have served as IAMC project co-chairs. It has been our great privilege to participate in these exciting efforts. We believe that such research puts our association at the forefront as thought leaders and innovators in the industrial real estate space.

Ron Grossmann, Novartis Pharmaceuticals Corporation
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EXECUTIVE SUMMARY

What do fighter jets, bicycles, and plumbing supplies have in common? More than one might think—particularly when it comes to the vast supply chain implications that manufacturers of these products will face as technological advancements, demographic changes, and shifts in the customer-producer dynamic take permanent hold in the coming decades.

"Roadmap for Change: The Flexible Industrial Distribution Facilities Network of the Future" details the work of a top-notch team of industrial architects and engineers who set out to explore and understand these massive changes, which are already underway. They aimed to reimagine today's disconnected and underperforming industrial distribution facilities as a nimble, networked system that can accommodate future change and the increasingly customer-centric direction in which businesses are going. The concepts presented in the paper are grounded in reality but draw on an imaginative forecasting of the state of society, looking out 25–50 years. The paper is the third in a series, part of the DesignFlex2030 initiative sponsored by the Industrial Asset Management Council (IAMC) and the Society of Industrial and Office Realtors (SIOR).

The paper addresses ways to reimagine existing obsolete warehouse space, offers innovative solutions to the problem of rising industrial lease rates and land costs, and provides approaches that can help revitalize stagnating pockets of communities and reverse urban blight. More broadly, the paper proposes concepts that future-proof distribution facilities across the range of manufacturing sectors—from aeronautics to plumbing fixtures—helping to strike the balance between cost-effectiveness and growing demand for just-in-time delivery.

First, the paper explores the trends that are upending the supply chain and the impacts they will have on distribution-related facilities. It identifies six key disruptors and ways to accommodate change: global migration to ever-larger megacities; self-orchestrated supply chains; robotics and automation; autonomous logistics and new modes to move people and things; and smart technologies and the Industrial Internet of Things or IoT.

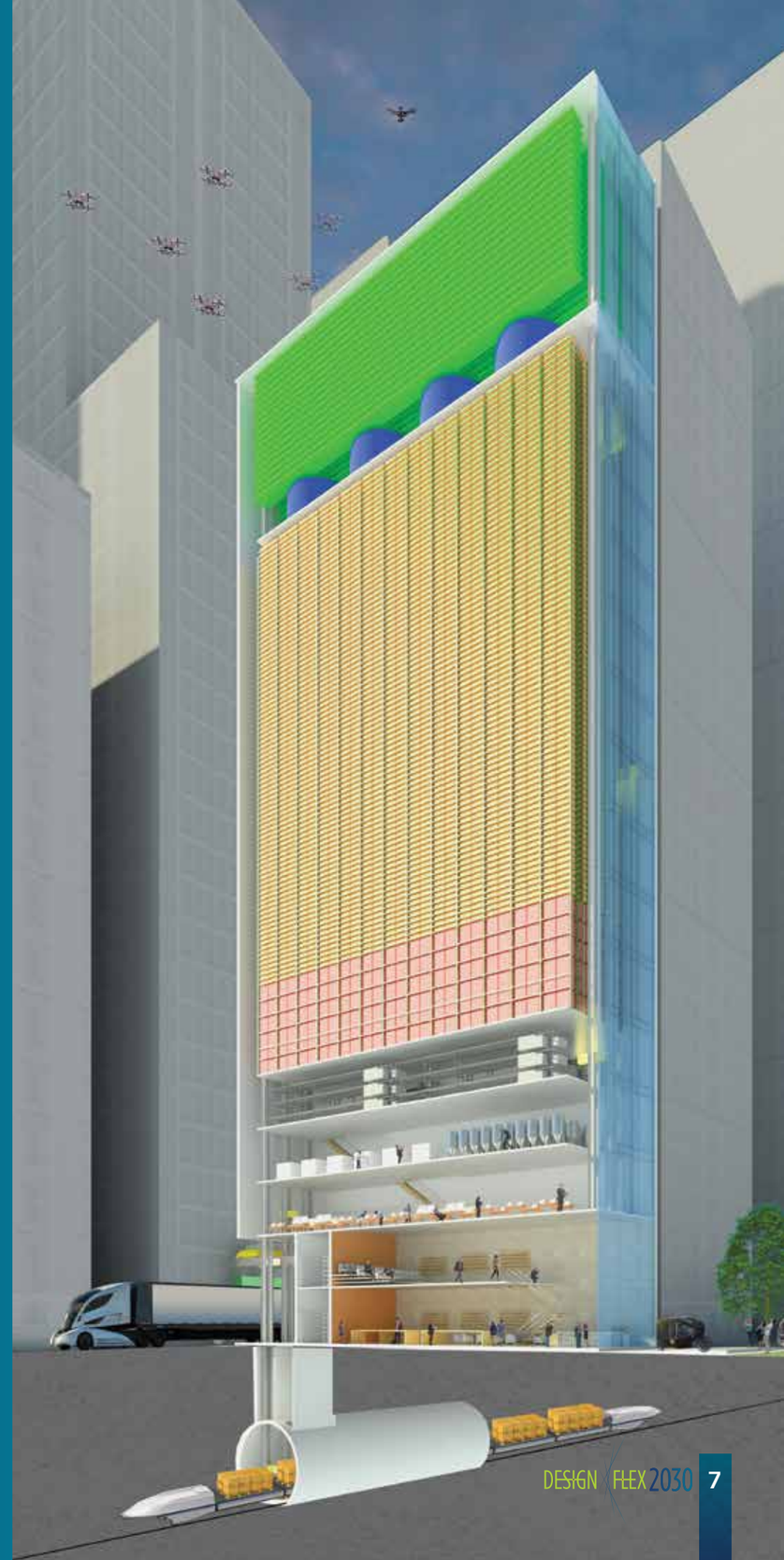
Next, the paper showcases entirely new warehouse and distribution facilities concepts, marrying world-class art and industrial design with elegant form and highly efficient function. As envisioned by the DesignFlex2030 team, the new network is a connected web of multiple fixed and mobile facilities, varying in size, shape, function, and scope, strategically located at various points along the logistics journey between OEM and end users in a 24-7 network, unconnected to a 5-day/8-hour workweek. It transforms overlooked and underutilized space—along with the air above and ground below—into a new industrial real estate resource that can be deployed for multiple uses as the lines between factory and warehouse blur.

With flexible elements embedded in each of the facilities, the individual buildings and the network as a whole represent a dramatic departure from traditional warehouse design approaches. The concepts enable continuous reinvention to accommodate anticipated and unforeseen change. Emphasis is on optimizing routes and modes to get product from manufacturer to end user more quickly and cheaply than anyone else. Entirely new designs include a reimagining of existing distribution centers as factories of the future, live-work-play developments with underground industrial uses, and hyperlocal, urban resource centers with placemaking appeal and highly efficient warehousing capabilities.

The next section of the paper looks at opportunities to address key challenges that will become even more pressing for communities in the future: what to do with obsolete commercial, warehouse, and retail space, how to meet growing demand for industrial space in proximity to population centers, how to address traffic issues caused by the conflicting demands of freight delivery and pedestrian-friendly development, and how to attract redevelopment to blighted quadrants of cities through innovative ways to build out small vacant parcels.

Finally, the paper identifies areas for future research. It concludes with an important observation that no two supply chains are the same. The paper does not offer a single, one-size-fits-all prescriptive for every company in every industry, as they face an uncertain future. Rather, it provides suggestions for concepts and approaches that can be customized depending on industry, market, and company specifics, using flexibility as a core construct.

The DesignFlex2030 distribution facilities design team includes two premier architectural and engineering firms: Heitman Architects, whose design for Trumpf Company's smart factory graces the cover of the December 2017 issue of Architect magazine; and Ghafari Associates, which took 2017 "Design Firm of the Year" honors at ENR's Midwest awards ceremony.



The hyperlocal urban resource center provides cities with same-day fulfillment.

INTRODUCTION



Repurposed warehouses become factories of the future producing on-demand goods.

This is the age of the empowered customer. Enabled by the universe of technologies that turns the twentieth-century notion of just-in-time delivery on its ear, business-to-business customers and consumers alike have an expectation of near-instantaneous order and delivery cycles. They want exactly what they want, exactly when and where they want it. And if they don't get what they want, they can swiftly deploy yet another technology-enabled weapon in their empowerment arsenal to let the entire world know of their dissatisfaction: social media.[1] Companies across the range of industries have been brought to their knees by social media firestorms created by customers unhappy about some aspect of product or service performance.

True, customers have always had a measure of power—voting with their wallets. But manufacturers used to have a greater degree of control. They determined product specifications. They set the timing and location of deliveries. If a business or an individual consumer wanted something different, they could probably get it—as long as they were willing to wait and pay more for the privilege.

Today, customers have found their voice and expect it to be heard. They want to be involved in creating products to meet their own specifications, arriving at a time that fits into their schedule and at a location most convenient to them. And they can be—aided by digital tools that enable broader access to information and real-time communication, the growing sophistication of 3-D printers that allow for additive manufacturing to customize products, highly efficient distribution models that place goods closer to end users for ever-narrowing delivery windows, and an electronically connected and automated universe independent of human workweek schedules to process and fulfill orders.

These technology trends will inevitably challenge and change many paradigms in the supply chain, according to Materials and Logistics Handling, a leading logistics association. In fact, the changes are already beginning to play out. One of the key changes is that "inventory is no longer a fixed concept," notes Matthias Winkenbach, director of MIT's Megacity Logistics Lab. "The customer wants you to deliver direct to where they are. Outlying bricks and mortar spaces are not equipped to facilitate that in the time frames that customers are expecting."

Technology trends will challenge and change many paradigms in the supply chain.

[1] Deloitte UK, "The Growing Power of Consumers," Deloitte Consumer Review, 2014



Warehouses of the future with on-demand additive manufacturing capabilities are co-located in multi-modal centers for efficient transfer of goods.

TRENDS WITH LEGS

These trends are gathering momentum with each passing day. Retailers are shifting from the notion of inventory stock to inventory flow. They are reducing the amount of goods stored and the amount of time they remain in storage while beefing up their logistics networks to move goods from point A to point B. [2]

The paradigm shift extends to production as well: Sophisticated 3-D printing and other additive manufacturing techniques are enabling cost-effective and swift customization. In some cases, this eliminates bulk production entirely to yield "orders of one."

What is becoming standard practice for consumer goods is gaining traction within the industrial supply chain, as business-to-business customers put pressure on their suppliers to shorten the time frames between order and delivery.

In an uncertain future, one thing's for sure: The era of the vast, single-use, single-story, plain-vanilla warehouse is over.

THE END OF DISTRIBUTION AS WE KNOW IT?

While businesses of all sizes and industries are scrambling to keep up, distribution is being upended entirely. Some experts have suggested that in 30 years, the distribution industry as we know it today will disappear altogether. But that doesn't mean that demand for warehouse space is going to go away.

In fact, demand is rising. Major population hubs are driving a marked increase in industrial absorption.[3] The Journal of Commerce reports that as of first quarter 2017, US vacancy rates for warehouse and distribution space were at a 17-year low, with asking rents rising quarter over quarter since 2015.[4]

"The proliferation of online retail is creating structural shifts in the industrial sector through a reconsideration of retail space needs and supply chains," the JoC report states. Retailers are increasingly taking advantage of major savings by maintaining inventory off-site, even as they absorb vacant or underdeveloped properties in densely populated urban areas so they can store goods closer to their end users—and get them delivered faster.[5] This shift, combined with the lease-up of existing industrial real estate by e-commerce fulfillment centers, is putting upward pressure on lease rates for tenants in search of new industrial warehouse space.

Kohler, an American manufacturer of kitchen and bath products, is one such company experiencing this phenomenon. "In general, we have seen asking rates increase," notes Paul Bouschard, the company's global real estate portfolio manager. The Kohler team has managed to keep their costs down as they negotiate for more warehouse space. But that's not the norm, he says. "More product in more sectors is being stored, and warehouse vacancy is decreasing in some key markets, driving rents up." Bouschard also points to another sign of growing demand for warehouses across the industry sectors: an uptick in speculative construction of new warehouses in certain active regions.

WHAT DOES THE FUTURE HOLD FOR DISTRIBUTION FACILITIES?

Who will staff them?

What activities will happen inside?

When (and how) will goods get picked, packed, and delivered?

Where will facilities be located?

Why will they still be needed?

How will they connect through the supply chain from OEM to end user?

TODAY'S LEASING BUBBLE COULD BE TOMORROW'S GLUT

All of this activity is happening right now. Looking out 20–30 years, market cycles are sure to turn once again. The warehouse leasing bubble is likely to burst as the market adjusts to this new paradigm and asking rents stabilize. What will reduce the risk of a future warehouse glut? In this uncertain future, there are no 100 percent guaranteed mitigation strategies. But a flexible design approach that enables rapid reconfiguration of space as needs change can help, because one thing's for sure: The era of the vast, single-use, single-story, plain-vanilla warehouse is over.

The next section explores the reasons why.

[2] Material Handling & Logistics, "U.S. Roadmap for Material Handling & Logistics: Version 2.0," April 2017.

[3] Jones Lang LaSalle, US Industrial Outlook 2016, December 2016.
[4] Mongelluzzo, Bill, ,"US distribution and warehouse space scarcer and pricier," Journal of Commerce, June 13, 2017.
[5] Salustri, John, "Retail Changes Continue to Transform Industrial," Globe Street, July 24, 2017.

DISTRIBUTION DISRUPTORS

Virtually every aspect of the changing dynamic between manufacturer and customer comes with a disruption to the distribution function. Here, we look at a few of these key disruptors and how these disruptions impact warehouse facilities.

THE GREAT MIGRATION

People are moving to cities. As the children of the baby-boomer generation reach adulthood, they want urban-style, densely populated, mass-transit-accessible, live-work-play communities. As the boomers themselves retire, they want to leave behind their large suburban homes and reliance on cars in exchange for the freedom of urban accessibility.

This migration has already started, and experts predict that it will pick up steam in the coming years. The result will be ever-larger megalopolises that encompass multiple cities, connected by high-speed rapid transit systems. According to Global Economic Forum estimates, urban populations will increase from 4 billion to nearly 7 billion over the next 30 years.[6] Other projections suggest that by the year 2050, cities will be home to 67 percent of the world's people.[7]

These urban populations will generate much of the world's future economic activity. "In the future, two-thirds of global economic growth will come out of only 600 massive megacities," says MIT's Winkenbach. One example of the emerging megalopolis: "BosWash"—the corridor between Boston and Washington, DC, which today is responsible for about 20 percent of US GDP. By 2050, this mega-region will likely be home to nearly 71 million people, close to 18 percent of the US population. [8]

In China, plans are underway to merge nine already-huge cities in the Pearl River Delta to create a new, massive megacity called JingJinJi. With a current population of over 130 million, this planned link-up of Beijing, Tianjin and Hebei would be bigger than Japan by population, and larger than Uganda by area.[9]

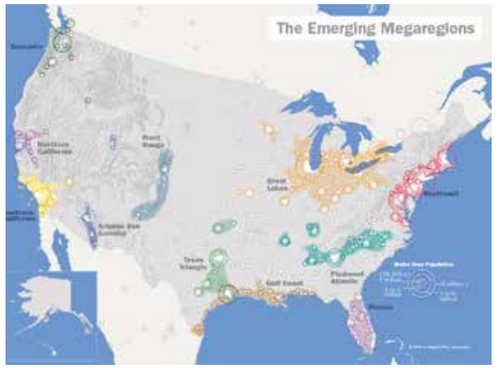
Following the Talent Trail

Given these changing demographics, companies that once embraced the notion of an idyllic and secluded suburban campus with vast acreage are rethinking their strategy. Acknowledging that such real estate won't be the draw for the best and the brightest it once was, firms are selling their suburban acreage in exchange for the admittedly tighter quarters of city centers.

In 2017, McDonald's was the latest corporate giant to concede that its massive, twentieth-century suburban campus represented an obstacle in its efforts to adapt to a twenty-first-century world. In July, the company announced plans to shutter its iconic Oak Brook headquarters and relocate to Fulton Market, a vibrant and revitalizing corridor of downtown Chicago. Others include Aetna, which is relocating its headquarters to Manhattan, and General Electric, which is moving out of Connecticut and building a new global headquarters complex in Boston. They are following the talent trail, leading them to city centers where, increasingly, workers want to live.[10]

More Things Delivered to More People in More Densely Populated Places

For industrial supply chains, the population shifts mean that efficiency along the last mile—from outside the city into the city center and from within the urban core to direct end-user delivery—will become harder to achieve using traditional freight transportation modes and approaches. It translates to a need for transformation, including inner-city warehousing capabilities and a new design approach. "Those in the logistics and distribution field will have to think about designing warehouses to fit into the urban landscape in the context of low land availability," Winkenbach says.



Emerging Megacities in the US



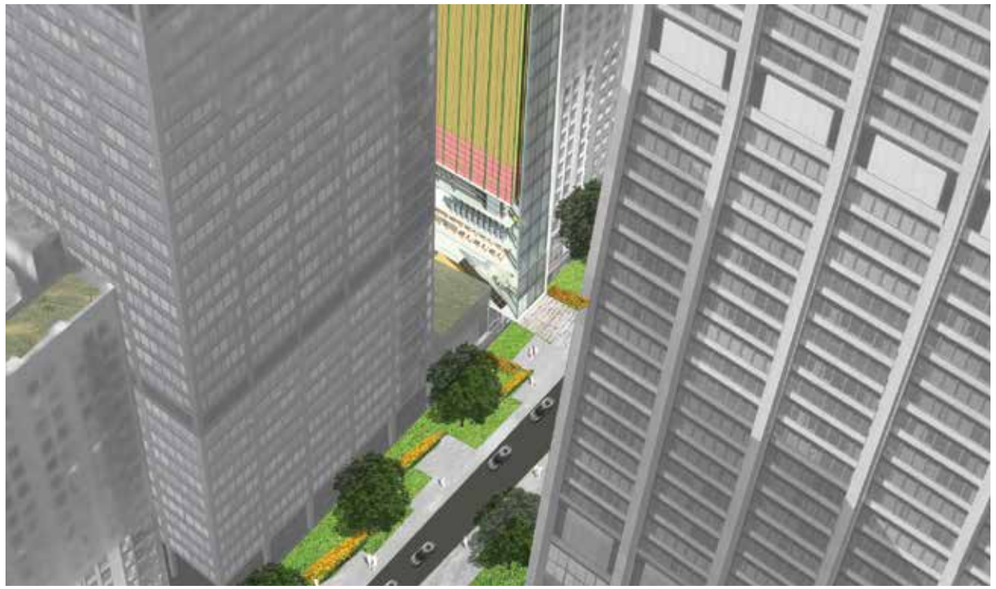
Potential US freight routes in 2050
source: America 2050

[6] World Economic Forum, "Top Ten Urban Innovations," October 2015.
[7] Newman, Galen, et al, "A current inventory of vacant urban land in America," Journal of Urban Design,Vol. 21, Issue 3, April 2016, page 307.
[8] Statistics based on information from regional planning agency America2050 and from Pew Research Center: See "10 Projections for the Global Population in 2050," February, 2014.
[9] World Economic Forum, "The 10 Fastest Growing Megacities in the World,", November 2016.

[10] O'Connell, Jonathan, "Suburbia is left scrambling as firms relocate to big cities," The Washington Post, July 16, 2017.

DISRUPTOR: MEGACITIES

What it will do	Impact on warehouse design	How to accommodate change
• Increase just-in-time local delivery volume • Alter approaches to urban design to accommodate mass transit and pedestrian-friendly street grid • Eliminate parking • Shrink street widths • Heighten public pressure to address truck traffic and congestion • Push for more certainty in last-meter delivery	• Hyperlocal fulfillment • Exurban feeder warehouses to supply hyperlocal centers • Underground and rooftop freight access	• Multiple smaller hyperlocal centers • Vertical construction to keep land costs down • Use of "undesirable" space for warehouse needs • Public-private partnerships to modernize transportation grid, including investments in new types of transport



The proposed hyperlocal urban distribution center fits seamlessly into cityscape.

DIGITAL REVOLUTION

The rise of e-commerce is a primary reason for the growing demand for new warehouse space, strategically located within closer proximity to consumers. In 2017, e-commerce combined with third-party logistics activity linked to online fulfillment represented about 40 percent of US industrial leasing activity.[11] This figure is expected to grow even as retailers close their physical doors by the thousands and shopping malls shut down entirely: Analysts at Credit Suisse estimate that more than 8,500 stores will close in 2017 and about 25 percent of the nation's shopping malls will close within the next five or so years.[12]

The digital revolution and the rise of social media have given customers tremendous power and control, triggering a new form of self-orchestrated supply chain. On-demand ordering and fulfillment has shifted the power dynamic so the customer is king. If companies routinely fail to live up to promises—say, a two-hour delivery window—the reputational damage could be severe.

Companies will need to be ever more responsive to customers who are coming to expect reliable, controllable just-in-time delivery. They will need an approach that reduces the uncertainties in last-mile deliveries so they are less vulnerable to traffic jams, weather events, or other unforeseen circumstances that cause delays.

In the context of a dense and digitally connected megacity, this will create a pressing new need for inner-city, hyperlocal fulfillment centers, according to Winkenbach.

DISRUPTOR: SELF-ORCHESTRATED SUPPLY CHAINS

What it will do	Impact on warehouse design	How to accommodate change
• Gap between ordering and processing is within seconds • Same day delivery becomes same-hour delivery • Unbundled supply chains	• Hybrid space needs • Reduced inventory volumes • Smaller warehouse size	• Open space to accommodate mix of uses • Sensors and digital connectivity • Revised location calculus for better proximity to manufacturer and end user

[11] Jones Lang LaSalle
[12] Wahba, Phil. "Major Wall Street Firm Expects 25% of U.S. Malls to Close by 2022," Fortune, May 31, 2017.

MATERIALS HANDLING: AUTOMATION, ROBOTICS, AND ARTIFICIAL INTELLIGENCE

The sea change in materials handling brought about by automation and machine learning is what will power the two-hour-fulfillment-window standard in the future. Sophisticated algorithms will help maintain appropriate inventory flow so the right goods get to the right place at the right time. Automated systems and robots will enable lights-out warehouse facilities, capable of processing orders 24 hours a day, seven days a week, with few human workers on site.

DISRUPTOR: ROBOTICS AND AUTOMATION

What it will do	Impact on warehouse design	How to accommodate change
• Alter assembly lines • Automate dangerous, repetitive, tedious tasks • Fill labor gaps • Increase productivity, quality, and speed with 24-hour, lights-out operation • Enable efficient last-meter delivery in traffic-congested communities • Decrease "single points of failure" • Provide seamless transfer of data and information • Enable real-time analysis for improved decision-making	• Lights-out warehousing • Increased shipment weight • Fewer corridors for walking • Fewer restrooms • More charging stations • Smoother floors • Rooftop communications systems • Scalability • Indoor temperature differential • Insulation from elements • Self-generated back-up power • New inventory storage patterns and flow of goods • High density • Sensors, scanners, and readers • Electronic monitoring center	• Mini-automated DCs • Smaller footprint • High ceiling heights • Vertical construction • Warehousing as part of a mix of uses • Leverage existing space to accommodate fulfillment and returns • Investments in next-gen fiber optics, digital photonics, and alternative energy

ADDITIVE MANUFACTURING

In 2014, sales of industrial-grade 3-D printers in the United States constituted one-third of industrial automation and robotic sales. Some projections have that figure rising to 42 percent by 2020.

Local Motors, which developed the world's first 3-D printed car, says that the process yields significant advantages: the ability to produce parts directly from a CAD file, elimination of investments in tooling, reduction in time lag between design and production, and elimination of penalties for redesigns—unlocking mass customization that was previously unobtainable.[13]

Already, companies like Lockheed Martin are focused on the industrial-scale potential of 3-D printing. The company has perfected digital fabrication methods to enable manufacturing directly from an engineering model, substantially reducing production time. In addition to incorporating such techniques into its own manufacturing processes, the company is providing digital manufacturing service offerings to other industrial customers that want to cut down their production cycles. While it is still early days for such technologies, Robert O'Brien, president of Lockheed Martin Corporation/LMC Properties, sees a day when the entire traditional manufacturing and storage process could be altered by digital fabrication—even for massive military fighter jets and satellites. "Thirty years from now, we'll probably be printing at least some components on demand, right there on the factory floor."

Major Implications for Inventory Management

According to Richard D'Aveni, a management consultant and professor at Dartmouth's Tuck School of Business, "Additive manufacturing is one of the biggest issues inside the manufacturing universe." In the future, increasingly sophisticated digital production capabilities could help address some current logistics and supply chain challenges faced by manufacturers, he says.

One such challenge is the need in some industries to maintain vast spare parts inventories. For instance, to retain its innovative edge, Kohler introduces new products every year. But the company also continues to support older products with replacement parts. This yields quite a variety of SKUs, according to Bouchard. "There's only a finite amount of shelf space," he says. "How do you continue to support these older products while adding to the inventory with spare parts for the new products that come out every year—and then managing these inventory levels?" The ever-growing spare parts inventory is a primary reason that company is looking to double the amount of its warehouse space, he says.

Q. What is additive manufacturing?

A. It's a process using digital design capabilities and machinery to print 3-D objects, involving the addition of layer upon layer of a raw material such as plastic, metal, or concrete, to build the object, guided by 3-D modeling software.

[13] Local Motors website

Solution to Legacy Product Challenge

Lockheed's O'Brien says that his company also faces challenges in maintaining inventory for their legacy programs. Of course, fighter jets and satellites are a lot different from plumbing fixtures. Still, the warehousing-of-parts issue is the same. O'Brien believes that the solution could lie in additive manufacturing. "I see major opportunities for additive manufacturing in the future to help sustain some of our legacy programs, such as the F-16 fighter jet," he says. "The warehousing implications would be huge, because we could use that space for something else, or just have a smaller warehouse." Similarly, Lockheed's one-of-a-kind products, like satellites, ultimately could be custom-produced on demand, without the need to set aside dedicated production space.

As Technology Evolves, Cost Decreases

At present, a course shift from traditional production methods to digital manufacturing currently entails significant upfront cost: Industrial printers can run upwards of $500,000 in an initial investment.

As with earlier electronic innovations, however—computers, flat screen televisions, smart phones—the cost of 3-D printing technology is likely to decrease substantially even as quality improves. In the coming decades, experts predict that it will be about 40 percent cheaper to print commoditized goods than to produce them in the traditional way. Today, additive manufacturing represents only 3 percent of the $12 trillion manufacturing market.

3-D PRINTING IS BLURRING THE LINES BETWEEN MANUFACTURING AND DISTRIBUTION

✓ The U.S. military deploys drones that are 3-D printed on demand in war zones.[14]

✓ Amazon's patented digital 3-D manufacturing system can produce clothing on demand after a customer places an order online.[15]

✓ Zimmer Biomet's 3-D printed artificial ankle implant replaces traditional surgical plates, screws, and staples, so surgeons can instantly customize implants in the operating room.[16]

✓ Lung Biotechnology artificially manufactures lungs and other organs for transplant using technologies including 3-D printing.[17]

✓ UPS is building on its existing third-party logistics business to turn its airport hub warehouses into mini-factories.[18]

[14] D'Aveni, Richard, "The 3-D Printing Revolution," Harvard Business Review, May, 2015.
[15] Dolan-Del Vecchio, Eric, "Amazon Wins On-Demand Patent; Moves Deeper into Manufacturing," Bisnow National, April 19, 2017.
[16] Zimmer Biomet press release
[17] Bruns, Adam, "Lungs on Demand?" Site Selection, August 2016.
[18] D'Aveni

Given the rapidly maturing technology, increased availability of raw materials, and steadily declining costs, there likely will be significant expansion ahead.[19]

Merger of Factory and Warehouse

As industries embrace additive manufacturing technologies, the lines between factory and warehouse will blur. Single-use warehouses will become increasingly obsolete. They will give way to hybrid facilities connected through the cloud to a customer service and inventory management platform. They will have the capability to receive and store bulk products, house a 3-D printer farm to customize individual orders placed through online applications, ship out the completed product, provide repair services, and offer customers a showroom experience.

Elimination of Spare Parts Inventory

Spare parts are one of the "low-hanging fruits for 3-D printing applications," says D'Aveni. As the technology takes hold, he anticipates a massive shift in the way spare parts of all kinds are produced. In the very near future, most spare and replacement parts will be printed on-site—on the factory floor or in a hybrid facility that might include storage, production, and a customer showroom, D'Aveni predicts. While the raw materials for 3-D printing—such as rolls of plastic filament and powdered metals—will require storage, they won't need as much space. And as the spare parts inventory disappears the amount of space needed for storage and warehousing will be drastically reduced.

From his perch at Lockheed, O'Brien, too, believes that traditional manufacturing of spare parts is on its way out. "At the macro level—not just for us, but for all manufacturers—I expect that there will be a fair amount of disruption in the spare parts supply chain as additive manufacturing technologies get perfected."

What the new raw materials will look like and what type of specialized storage they will require are questions that will be answered as the technology comes of age. Given the range of uncertainties swirling around the entire distribution network, however, there is a clear need to embed flexibility into the entire facilities value chain. Starting at the factory and ending with last-meter delivery, that flexibility will enable rapid and cost-effective repurposing and adaption as facilities needs change.

"At the macro level—not just for us, but for all manufacturers—I expect that there will be a fair amount of disruption in the spare parts supply chain as additive manufacturing technologies get perfected."

—Robert O'Brien, president, Lockheed Martin Corporation/LMC Properties

[19] D'Aveni

DISRUPTOR: ADDITIVE MANUFACTURING

What it will do	Impact on warehouse design	How to accommodate change
• Enable on-the-spot customization • Make order-of-one production viable and cost-effective	• Hybrid space for factory and warehouse • Upscale exteriors: with locations closer to end users, increased need to seek community buy-in on design • Altered storage space needs • SKU reduction	• Open space for more flexibility • Flat floors to support heavy 3D printers • Few structural impediments to allow for rapid change of uses

TRANSPORT: NEW WAYS TO MOVE PEOPLE AND THINGS

The advent of next-generation transportation modes is upending the traditional ways in which people and things get from place to place. High-speed rapid transit will further accelerate demographic shifts, connecting urban nodes within a megalopolis and transporting people and things at previously inconceivable speeds. In China for example, work has begun on a new iteration of the magnetic levitation train, which could exceed speeds of 360 miles an hour. Already, Shanghai's maglev trains transport people between the city and Pudong International Airport at speeds exceeding 250 miles per hour. Japan, too, is experimenting with next-generation maglev technology.[20]

In the United States, Elon Musk, the CEO of Tesla, Inc., is exploring an underground pneumatic tube system that would initially connect dense urban centers along the East Coast and West Coast. In July 2017, Musk said that the system could transport people from Washington, DC, to New York City—a distance of 250 miles—in 29 minutes. While it may seem far-fetched, Maryland state officials recently approved permits that allow the company to start digging.[21]

Such systems aren't limited to transporting people. A Musk company, Hyperloop One, is conducting feasibility studies at the ports of Los Angeles and Long Beach and at Dubai's Jebel Ali Port for a freight hyperloop system. Other efforts are focused on high-speed freight maglev systems and electric freight shuttles.[22]

[20] Hawkins, Andrew, "China is building a magnetic levitation train that can go an insane 373 mph," The Verge, November 1, 2016.
[21] Banister, Jon, "Elon Musk's New York-to-DC Hyperloop to Begin Construction in Maryland," Bisnow, October 20, 2017.
[22] Marshall, Aarian, "Forget Hyperloop: This Awful Looking Thing Can Move Your Stuff," Wired, October 10, 2016.

Transformational Logistics Technologies

The world of autonomous logistics is expanding rapidly, with solutions already in use or in development for warehousing, materials handling, cross-docking, and hauling. Among the products available now or coming soon: autonomous guided vehicles (AGVs), autonomous cranes, mobile robots, drones, autonomous ships, trucks, and rail, truck platooning, and self-driving cars.

As with earlier generations of technology, such systems were originally developed for military uses. Lockheed, which produces drones and other autonomous vehicles for the military, is now seeing an uptick in commercial interest for such products. For example, in response to growing demand, the company's Sikorsky division is prototyping an autonomous helicopter for commercial use. It's based on Sikorsky's unmanned military chopper, created to ferry supplies to troops in the hard-to-reach mountain passes of Afghanistan. The message here, says Lockheed's O'Brien: "If you don't believe these technologies are coming your way, and sooner than you think, trust me, they are!"

Aside from the cost associated with constructing next-gen infrastructure to accommodate the explosion of new transportation modes—no small thing—the challenge will be achieving effective interaction between humans and machines. "How can we equip structures to facilitate autonomous vehicle deliveries? Elegant human-machine interfaces will be critical," says MIT's Winkenbach.

DISRUPTOR: AUTONOMOUS LOGISTICS

What it will do	Impact on warehouse design	How to accommodate change
• Reduce reliance on traditional shipping modes • Increase logistics options • Enable two-hour delivery window and last-meter delivery in urban locations	• Configuration of loading docks: to accommodate autonomous and traditional modes • Location calculus: not as important to be near highway/rail	• Sensors and handling mechanisms throughout the built environment • Flexibility to alter loading dock designs • Internal gantry cranes to lift/lower trailers



By 2030, high-speed rapid transit will connect all US megacities for increased mobility of people and things. Source: US High Speed Rail Association

THE 4TH INDUSTRIAL REVOLUTION AND THE INTERNET OF THINGS

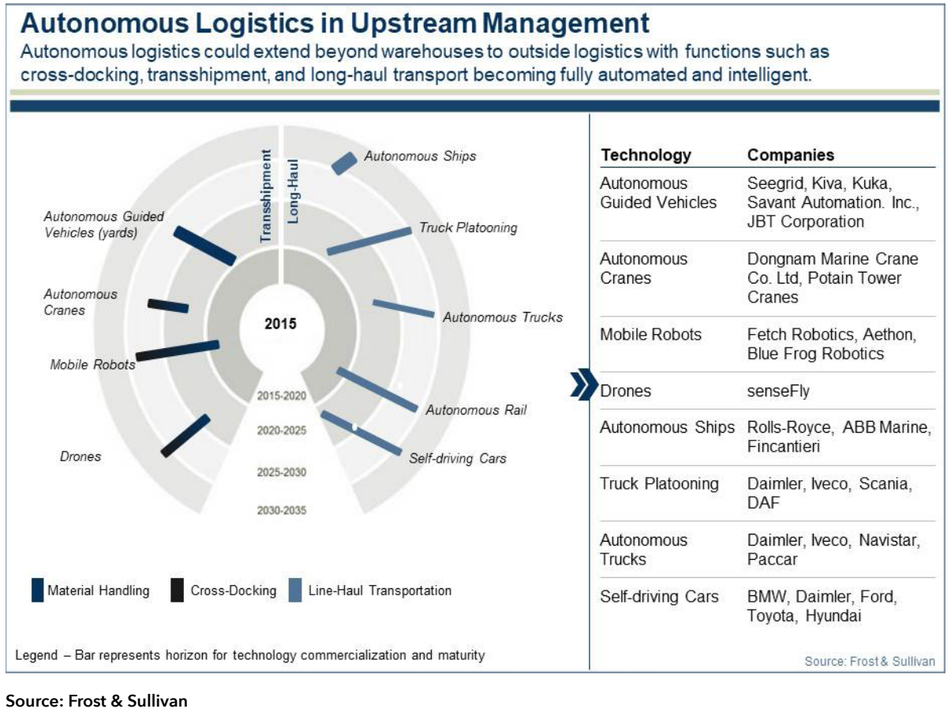
Networked sensors allow companies to monitor the condition of products from even before the point of manufacture to final delivery and at every point along the way. Rafts of real-time data flow to electronic platforms that instantly analyze the information to optimize delivery routes, allow for smart inventory management, and enable autonomous replenishment.[23] Sensors connect robotic pickers and packers, as well as autonomous vans and "deliver-bots" for real- time monitoring of last-meter delivery progress. This completely connected universe—also known as the Industrial Internet of Things (IIoT) or the Internet of Things (IoT)—also enables levels of embedded flexibility never before possible in the built environment. Digitally programmable walls can be reconfigured with the touch of a button. Fully equipped modular units can slide in, slide out, and instantly link up with adjacent modules for ease of reuse.

Rooftops can automatically retract for delivery from dirigible or drone above. All such capabilities offer the potential of longer-term use and reduced need for new construction.

Smart Cities and Connected Ecosystems

Well beyond the obvious logistics and distribution industry implications, these

[23] Tomas, Juan Pedro, "How is the IoT revolutionizing supply chain management?", Enterprise Insights, June 23, 2017.



Source: Frost & Sullivan

smart technologies will have sweeping impacts, affecting all kinds of interactions: people-to-people, people-to-things, and things-to-things. They are starting to play a role in the kinds of public infrastructure that are built into new communities.

In Denver, the new $500 million Peña Station Next mixed-use development is envisioned as a fully connected ecosystem—where everything from lighting to offices to public transport to parking meters will feature cameras and sensors, feeding a continuous stream of data to cloud platforms.

In North Carolina, the city of Wilson is looking at investments in such smart cities technologies, as a way to enhance quality of life, improve public infrastructure, and optimize the movement of people and things throughout the city. "We think smart technologies are going to transform the way cities function," says Jennifer Lantz, executive director of the Wilson Economic Development Council. "We are investing in smart cities initiatives that will prepare us for this more connected future."

Connectivity Requires Investments in IoT Infrastructure

This connected universe is only as effective as its weakest link. What if the power goes out? What if the Wi-Fi is down? What if the cloud platform is over capacity? The ensuing domino effect of supply chain, logistics, and materials-handling failures could cause

major headaches for a company trying to get goods where they are going. As manufacturers and logistics providers alike increasingly embrace the IoT to optimize functions such as logistics, warehousing, supply, and delivery, they will need to put in place several critical elements:

- Data storage capacity: With exabytes of data flowing and demand for cloud storage increasing, data centers are already a part of the critical infrastructure. As the connected world grows and expands, so too will the need for storage.
- Redundant and backup power: To mitigate risks and avoid such costly failures anywhere along the supply chain, future manufacturing and distribution facilities will likely include self-generating capabilities, making use of solar and other alternative energy technologies.
- "Sensorfication" of the built environment: Scanners, sensors, and other connecting tools will be everywhere. Facility design will need to account for such equipment, including use of construction materials that facilitate—rather than obstruct—optimal Wi-Fi signal strength, to ensure seamless, swift, and reliable electronic communication and data flow.
- Analytics: To truly tap into the potential of big data in optimizing their logistics and distribution, companies will need to identify ways to organize, understand, and make use of the massive data streams coming their way. In fact, this is already happening: One recent international survey of more than 1500 supply chain executives revealed that about 60 percent are planning new investments such technologies. [24]

DISRUPTOR: INDUSTRIAL INTERNET OF THINGS

What it will do	Impact on warehouse design	How to accommodate change
• Trigger real-time continuous information flow from devices everywhere to and from DC • Optimize inventory management • Optimize supply and delivery modes/routes, including last-mile/last-meter	• Inventory management • Pick and pack • Autonomous Guided Vehicles (AGVs) • Automated Storage and Retrieval Systems (ASRS) • Delivery	• Human/machine interfaces • Sensors and handling mechanisms • Intelligent facilities management platforms • Investments in next-gen fiber optics, digital photonics, and alternative energy • Data storage capacity

[24] Handfield, R., et al, "Trends and Strategies in Logistics and Supply Chain Management—Embracing Global Logistics Complexity to Drive Market Advantage," BVL International, Bremen, 2013.

ADDITIONAL DISRUPTORS

Other changes already underway that could influence the way distribution facilities are designed, used, and located in the future include shifts in inventory strategy and flow,[25] bionic enhancements, blockchain technologies, wearables such as Google Glass, and waste management transformations, including upcycling of waste materials for new uses.

TOP CONSIDERATIONS FOR INDUSTRIAL WAREHOUSE LOCATIONS TODAY AND TOMORROW

- ✓ Corporate tax implications
- ✓ Proximity to manufacturing centers
- ✓ Proximity to direct/indirect customers/distributors/end users
- ✓ Proximity to logistics provider hubs
- ✓ Quality workforce availability and stability
- ✓ Facility infrastructure to support automation technologies
- ✓ Import/export regulatory considerations
- ✓ Flexibility of loading dock design and traffic flow to accommodate variety of processes and transportation modes

Source: DesignFlex2030 team resources

[25] Enterprise Insights

THE FLEXIBLE, 24/7, INDUSTRIAL DISTRIBUTION NETWORK OF THE FUTURE

Today's distribution facilities are already obsolete. That's the fundamental problem: Given the massive disruptive factors upending the industry, today's warehouses are not equipped to accommodate the rush of change already coming.

They're not in the right places. They're not the right sizes. And they lack the flexibility to accommodate the mix of activities that will need to happen inside, from additive manufacturing and order customization to fulfillment, repair, and return.

In designing the new network, the research team considered three questions on the minds of industrial owners and users of warehouses today:

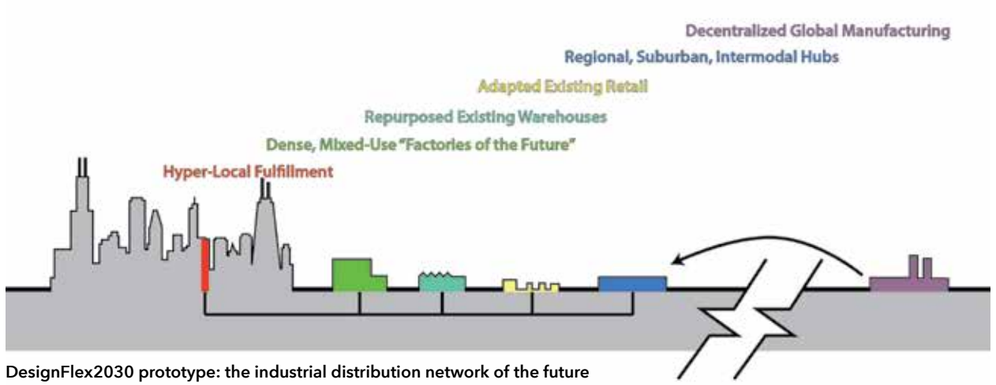
1. What am I going to do with my existing obsolete and increasingly unviable warehouse space?
2. What does the future hold for distribution?
3. What kind of future-proof distribution system will meet my needs in a rapidly changing environment and strike the balance between cost-effectiveness and growing demand for just-in-time delivery?

A CUSTOMER-CENTRIC, EFFICIENT, AND COST-EFFECTIVE NETWORK

The proposed distribution network is an effort to answer these questions. It is a connected web of multiple fixed and mobile facilities, varying in size, shape, function, and scope, strategically located at various points along the logistics journey between OEM and customers in a 24-7 network, unconnected to a 5-day/8-hour workweek. With flexible elements embedded in each of the facilities, the individual buildings and the network as a whole can continually reinvent themselves, to accommodate anticipated and unforeseen change. Emphasis is on optimizing routes and modes to get product from manufacturer to end user more quickly and cheaply than anyone else. The proposed network would include:

- Global manufacturing centers: co-located research and development, warehouse, office; accessible via high-speed mass transit for employees; multi-modal freight shipping and receiving options
- Regional intermodal facilities: high-efficiency container movement, all-electric vehicles and intelligent automation; sorts and moves containers between modes just in time to designated freight carrier for the next leg of the logistics journey or delivers container to on-site, hybrid facility for parts assembly and storage[26]
- Repurposed and reimagined regional warehouse/distribution centers: multifunctional sites including showroom, repair center, assembly, and 3-D printing capabilities for additive manufacturing
- Live-work-play mixed-use development with warehouse component: new construction or adapted existing retail/shopping mall/office as e-commerce distribution center, customer pickup, service center; 3-D printer farm for customized manufacturing and spare parts production
- Hyperlocal, vertical lights-out hybrid center: retail, additive manufacturing, warehouse, online returns/fulfilment, urban farm

[26] Eagle Rail Container Logistics website



DesignFlex2030 prototype: the industrial distribution network of the future

REIMAGINED DISTRIBUTION CENTERS: TODAY'S WAREHOUSE IS TOMORROW'S FACTORY

These facilities are imagined as flexible retrofits of aging and obsolete warehouses. They are a practical response to the rapid shift in supply-chain dynamics due to digital connectivity and new consumer demands, requiring a shift from 8-hour, 5-day-a-week operating shifts to 24/7, lights-out automation. In essence, today's distribution centers become tomorrow's factories.

Modular, fully contained units can slide in and slide out to enable continuous upgrades as technology advances and needs change. The modular approach also allows the facility to accommodate different industrial needs at the same time.

Strategic Opportunity to Consolidate the Supply Chain

Powered by renewable energy sources, these new factories of the future will produce a variety of custom products upon order, using additive manufacturing technologies. Finished-goods inventory gets replaced with raw-ingredient supply storage. Parts are digitally produced on site with automated, on-demand final assembly. Special components are shipped from regional suppliers on freight rail. The concept represents a strategic opportunity for companies that are part of the same supply chain to co-locate, thereby significantly lowering their logistics costs and shrinking their delivery time frames. Meanwhile, larger-scale industrial products—bulk chemicals, massive steel beams, "white goods" such as refrigerators—could be stored easily for conventional transport to the next point along their logistics journey.

Located between five and fifteen miles from city center, these facilities become community supply hubs, connected to a network of mobile fulfillment vehicles. Multiple access points enable the range of supply and delivery modes, including sensor-embedded truck bays for docking of autonomous and semi-autonomous carriers.

RE-IMAGINED DISTRIBUTION CENTERS

- ✓ 150,000 sf on 8-acre site
- ✓ 40-foot clear ceilings
- ✓ Smart floors with embedded sensor arrays
- ✓ Zero structural impediments to enable modularity and multiple uses
- ✓ 3 service dock areas for aggregated shipping and receiving
- ✓ AGV support: inspection/charging
- ✓ vPowered by 600 KvA wind turbine, sun-tracking solar trees above on-grade parking
- ✓ 75,000 sf fully automated roof-top farm producing 500 tons of produce/year: Greenhouse structure extends growing seasons even in cold climates.

The facilities have the capacity to handle operations for three independent companies, working collaboratively under a single roof. It creates the potential to consolidate a supply chain spread across a 1,500-mile radius into a single facility, thereby significantly reducing logistics costs and time frame.

The rooftop becomes a piece of valuable real estate as well. With hydroponic farming capabilities, it could be leased to a local agribusiness for farm-to-table food supply.

Because of their large footprint and strategic locations, these reimagined community supply hubs also serve as recycle centers, breaking down post-consumer products and reintroducing them into new-product manufacturing.

Beyond net-zero consumption, the facilities generate excess power for the grid and replenish the local water supply through rainwater collection.

DENSE, TRANSIT-ORIENTED, MIXED-USE INDUSTRIAL HYBRID OF THE FUTURE

The design team deployed similar adaptive reuse concepts when considering the potential in obsolete corporate campuses, shopping malls, or blighted industrial land. They identified a way to create vibrant new transit-oriented developments in emerging fringe neighborhoods outside city centers, while accommodating manufacturers' and third-party logistics providers' needs for more close-in industrial space.

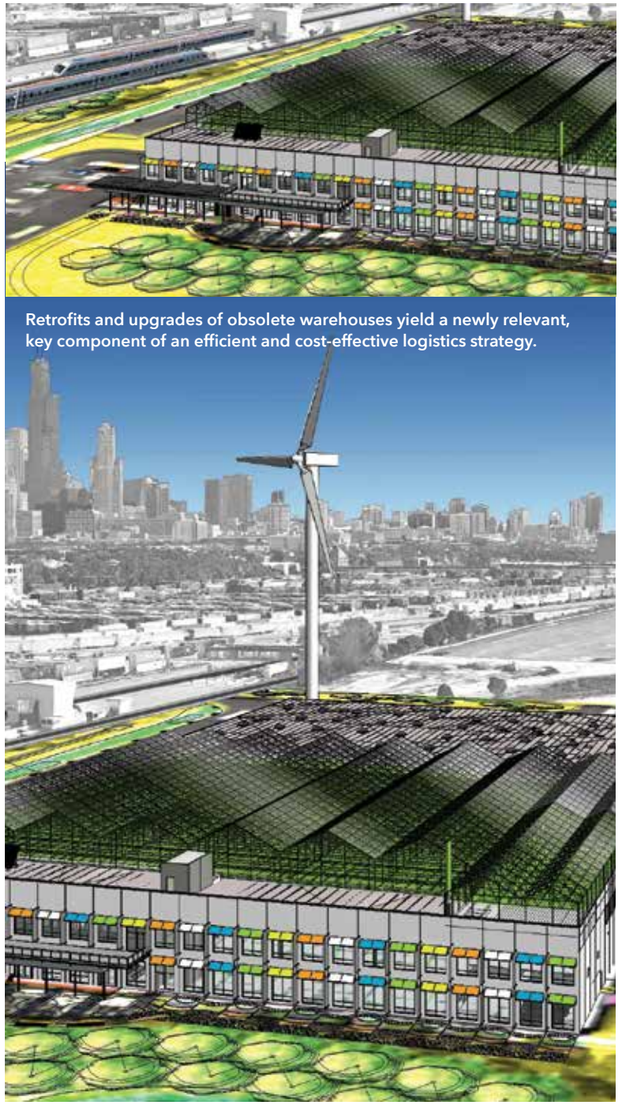
Designed for a population striving for better work-life balance, the new, 20-acre, live-work-play development includes an industrial component, tucked beneath high-end housing for next-generation urban dwellers.

A Way to Afford Higher-Value Land or Revitalize Blighted Industrial Land

"This is a perfect solution to the dilemma faced by many companies that want to locate warehouses closer to their customers: The closer into urban areas you get, the more expensive the land becomes," explains Karl Heitman, DesignFlex2030 team co-lead and president of Heitman Architects. This is a way to afford the land you need for your distribution and warehousing in places where land costs are high." Here, the residential component covers the cost of development. It creates a new financial rationale that alters the old commercial real estate conventional wisdom about not using higher value land for lower value purposes.

Adds Andrew Cannon, DesignFlex2030 co-lead and Ghafari's director of business consulting. "Housing is the important financial driver here. The idea is that you could take a large footprint of very valuable land, on which you develop residential, retail, and commercial, and which ends up paying for itself. You slide in the distribution component on the bottom level, basically giving you these industrial uses for free."

The design concept makes good financial sense in other scenarios as well: An assemblage of abandoned, obsolete properties at the city edge is catalyst for revitalization of blighted, low-density industrial sectors.



Retrofits and upgrades of obsolete warehouses yield a newly relevant, key component of an efficient and cost-effective logistics strategy.



Liveable, Walkable Community and Smart Warehouse Capabilities

The 400,000-square-foot footprint accommodates 40-foot clear flexible production space. Additive manufacturing, three-level pick modules, and Very Narrow Aisle (VNA) storage and retrieval systems operate invisibly under the virtual city above. An open configuration enables rapid change-out of uses: from warehouse to autonomous retail shop-on-wheels that slides into the same space as a pop-up bricks-and-mortar store, controlled via wireless mobile applications.

As new transportation infrastructure comes on line, the complex has the capability to accommodate new underground and in-the-air traffic patterns. Mechanisms are in place to move trailers to and from underground freight tunnels. Pedestrian accessways link residents to their city center commutes via hyperloop.

The apartment blocks sit above green decks that feature convenience retail shops, parks, playgrounds, and ball fields. A parking deck separates residential uses from clean industrial uses below.

LIVE+WORK+PLAY RESIDENTIAL COMPONENT

- ✓ 7 floors
- ✓ 122 units/floor
- ✓ 1-,2-, and 3-bedroom units, 1,500 sf average
- ✓ Rooftop docking
- ✓ Embedded smart-home array
- ✓ Dedicated residential ASRS connected to ground- floor warehouse
- ✓ for autonomous fulfillment
- ✓ Access to underground hyperloop
- ✓ Parking for spare shared-service AGVs

Transit-oriented, mixed-use development with flexible underground space for warehouse uses at city edge





INDUSTRIAL BASE OF MIXED-USE DEVELOPMENT

- ✓ 400,000 sf with 40-foot clear height
- ✓ Flexible 60-foot-by-50-foot bays
- ✓ Mix of industrial uses: three-level pick modules, ASRS systems, VNA and wide-aisle racking, additive manufacturing printer farms, repair
- ✓ Ability to convert to pop-up food hall, retail, or holiday mart
- ✓ Door openings to accommodate self-contained modules
- ✓ AGV support: inspection/charging
- ✓ 180-foot-deep service courts enabling cross-dock operations
- ✓ Underground freight rail/hyperloop connections to urban core for high-speed delivery to urban core
- ✓ 87 full-size semi-tractor trailer smart docks for semi-autonomous truck/self-driving trailers, with 4 drive-in ramps
- ✓ Gantry cranes to transfer trailers to and from freight tunnel
- ✓ Micro-depot and AGV support hub
- ✓ On-site storage for up to 85 53-foot trailers
- ✓ On-grade parking/landing pad/docking for up to 375 autonomous industrial vehicles

HYPERLOCAL URBAN RESOURCE HUBS

With lot-line-to-lot-line vertical construction and a building envelope that soars 40 stories but blends into the fabric of the cityscape, these facilities are built on small, vacant, and hard-to-develop parcels throughout the megacities. They meet the small-scale fulfillment requirements of the local residential and commercial population. They also can accommodate a range of other uses. Goods could be supplied via maglev skyway train or an underground pneumatic tube system that is connected to urban freight tunnels. Self-driving or semi-autonomous trailers also deliver through alleyways. They are lifted via gantry crane to upper floors for unloading. The 2,950-sf footprint replaces a 135,000-sf, traditional suburban distribution center based on volume capacity. Of note: It increases operational productivity by 75 percent, due to embedded efficiencies.

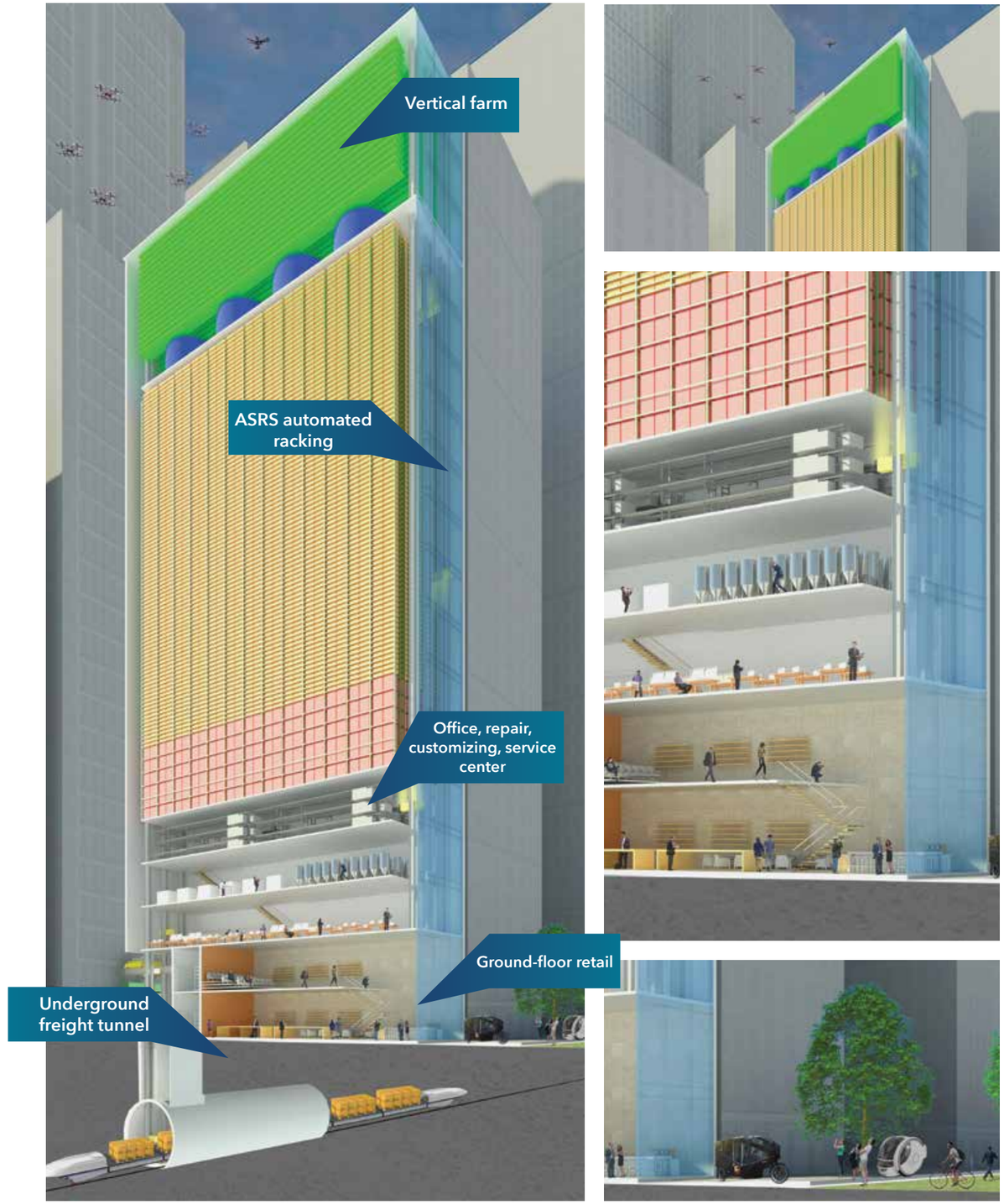
The street-facing building side is the only one visible. A transparent glass exterior allows views into the elegant machinery at work inside. Lit up by a colorful and changeable array of LED lights, the facility itself becomes a breathtaking piece of performance art.

The idea, says Karl Heitman, is to almost literally flip today's standard horizontal design on its ear. "The warehouse of today is really long and really thin. If you tip the whole thing on its side, you could fit one million square feet of horizontal warehouse into this really tall but really narrow vertical space as the perfect urban configuration." It is a revolutionary concept that quite literally takes the proverbial "sow's ear"—an unattractive warehouse—and turns it into a "silk purse"—placemaking public art.

Eliminating the Traditional Notion of Inventory

In this scenario, traditional inventory gets eliminated. Raw materials and product components are replenished by autonomous freight trains from the freight tunnel network below the streets. Drive-through receiving and shipping functions are handled by vertical-lift gantry cranes on one-way back alleys. The 40 floors of the building are designed to enable flexibility use.

- Below-ground area provides access and connections to underground freight network.
- Ground floors are pedestrian-oriented experience centers for shopping along streets converted to green, carless parkways within the central business district. The retail experience center offers virtual reality opportunities to further customize products in progress. It also serves as a recycle center, where obsolete products are returned, disassembled, and then recycled into new products on upper floors.
- Middle floors house additive manufacturing modules and final product assembly to produce custom, order-of-one products in real time. The system feeds last-meter delivery to urban consumers within hours of order placement.
- Upper floors serve as a warehouse with three aisles of vertical ASRS for parts sub-assembly components and raw materials that supply manufacturing below.
- Three top floors feature a multi-level aquaponic conveyer system that produces 500 tons of fresh produce annually.
- Rooftop real estate accommodates tilapia fish tanks that generate the nitrates needed for growing. The fish tanks serve another important purpose: as dynamic stabilizers to minimize the sway of the high-rise.

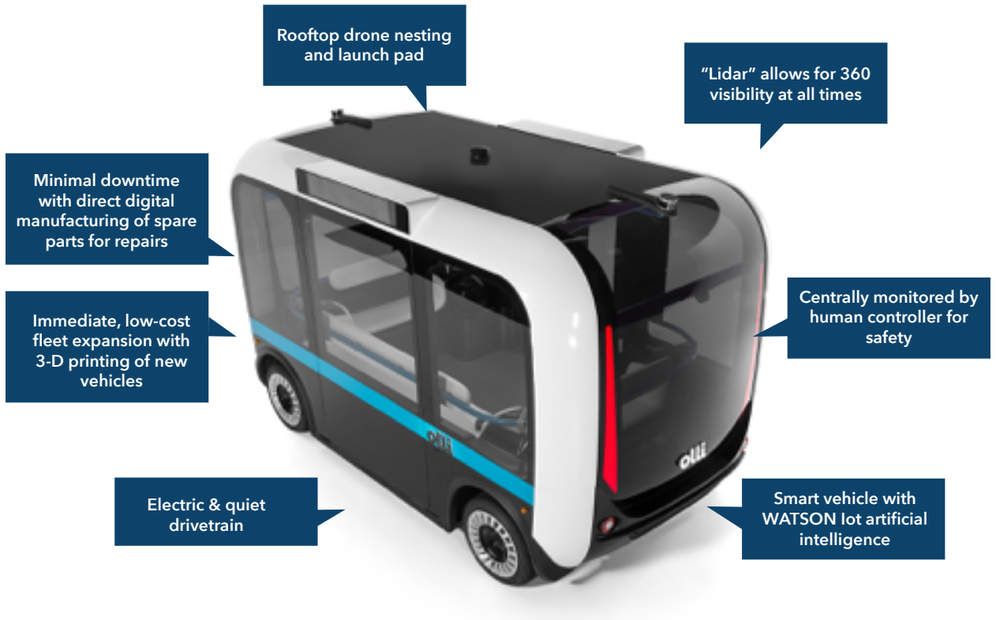


Cutaway detail of hyperlocal center shows the range of uses possible and placemaking appeal.



HYPERLOCAL URBAN RESOURCE CENTER

- ✓ 25-foot wide, lot line-to-lot-line construction
- ✓ 40 stories tall
- ✓ 2,950 sf
- ✓ Replaces 135,000 sf horizontal DC and increases productivity 75%
- ✓ Ground floor retail/e-commerce fulfillment and returns
- ✓ Middle floors for additive manufacturing and final assembly
- ✓ Vertical ASRS
- ✓ Glass exterior with embedded LED arrays
- ✓ Hypervelocity docks
- ✓ AGV charging support
- ✓ Micro-depot and delivery lockers
- ✓ Remote control center
- ✓ Multi-level aquaponic farm with 500-ton annual growing capacity
- ✓ Roof-top tilapia fish tanks: generate nitrates for growing solution and stabilize building to reduce sway



Autonomous vehicles traverse megacity streets on fixed routes for urban first- and last-meter delivery
Source: Local Motors

SOLVING THE LAST-METER DELIVERY DILEMMA

Already, the reality of getting goods directly into the hands of city dwellers is creating logistical headaches. "That last mile—including the last meter—is one of the most costly and complex steps in the supply chain," Winkenbach notes.

The network of the future addresses the issue head-on, as the proposed hyperlocal center becomes a new supply-chain node on a physical Internet distribution model. It replaces bricks-and-mortar facilities with a real-time, on-demand, Uber-like mobile delivery hierarchy. Roving autonomous "mother ship" trucks supply fleets of autonomous vans that circulate the city on 24/7, continuous routes. The vans carry goods along with a contingent of drones and robotic carts for last-meter/rooftop and doorman deliveries.

> **"Drone delivery might work for smaller goods, but it's not an across-the-board last-meter solution. You're not going to deliver a bathtub by drone, for instance—that would never be a good idea!"**
>
> **—Paul Bouschard,** global real estate portfolio manager, Kohler

With alleyway access and underground docking berths at the hyperlocal center, the motherships are lifted by internal gantry crane for automated replenishment, guided by artificial intelligence that identifies restocking needs through sophisticated, lightning-fast algorithms.

Suitability for Inner-City Distribution Center Depends on Product Type

Of course, certain types of industrial goods cannot be accommodated in the smaller confined spaces of a vertical warehouse—nor can drones or small robots handle last-meter delivery of all goods. "Drone delivery might work for smaller goods, but it's not an across-the-board last-meter solution," says Kohler's Paul Bouschard. "You're not going to deliver a bathtub by drone, for instance—that would never be a good idea!" For larger industrial goods or goods requiring special handling, such as bulk chemicals, the last-mile delivery would likely not involve these small centers. Instead, deliveries would be routed directly from the reimagined distribution center or the mixed-use development located at city's edge, depending on the goods.

Requirements of the New Network

"The keys to the kingdom in this new distribution world are global data, connectivity, redundant power, and efficient human-machine interfaces. If any of this falls short, the entire distribution network fails," notes Andy Cannon. "At the end of the day, this all becomes a highly sophisticated data-management exercise."

Here are some of the underpinnings of the new network:

Warehouse design enhancements. Going forward, warehouses will become a common component of mixed-use developments, requiring greater attention to aesthetics.

- High-quality external materials and visually appealing structural elements
- Building envelope that integrates into mixed-use design or cityscape
- Automated materials handling
- Flexible, adjustable internal spaces that can accommodate modularity and changing equipment
- Flat, reinforced floors that can support very heavy weight

> **"The keys to the kingdom in this new distribution world are global data, connectivity, redundant power, and efficient human-machine interfaces. If any of this falls apart, the entire distribution network fails. At the end of the day, this all becomes a highly sophisticated data- management exercise."**
>
> **—Andy Cannon,** director, business consulting, Ghafari

High-speed transit and alternative transportation modes. This will require significant public and private investment in upgraded and updated transportation infrastructure.

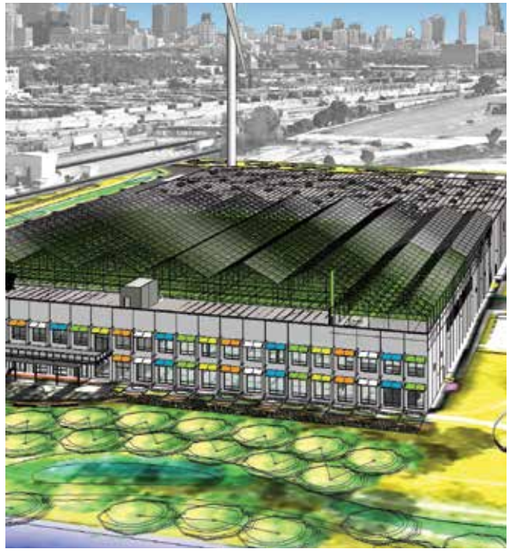
- New modes of freight transportation including autonomous/semi-autonomous trucks
- Autonomous fleet for last-mile and last-meter deliveries

Data and power reliability, high-speed connectivity, and security. Every aspect of the new network depends on connectivity.

- Sufficient and imminently expandable data storage
- Redundancy and backup
- Zero-failure points
- Data centers for cloud storage
- Underground power transmission to reduce risk of grid failure
- Beyond-password protection security: fingerprint/facial recognition/retinal scan

Fully networked built environment. The IoT will require:

- Sensors
- Landing pads for drones
- Additional interfaces and platforms
- Analytics capabilities





With increased proximity to population centers, future industrial facilities will need to include architectural enhancements for greater community acceptance.

OPPORTUNITIES AND CHALLENGES

With flexibility as a core construct, the team's proposed distribution network can accommodate near-infinite adaptation as needs change. It includes new construction. It also includes repurposing of older, unusable warehouse space as part of the kinds of mixed-use, live-work-play communities that will continue to be in demand even as the millennial generation that is driving today's push for walkable, urban-style communities moves towards retirement. The network as conceived offers opportunities to address several current challenges facing economic developers, city planners, and managers of corporate real estate portfolios alike.

Build-Out of Underdeveloped Urban Sites

The need for hyperlocal fulfillment in an increasingly urbanized world represents a significant opportunity to build out small patches of underdeveloped sites within downtown cores. A study by Dr. Galen Newmark, an urban planning expert and professor of urban architecture at Texas A&M University, and his colleagues offers some insight into the scope of the opportunity in the United States. The 2016 survey of vacant land and abandoned buildings in 70 US cities, published in the Journal of Urban Design, revealed that:

- Nationally, an average 16.7 percent of large US cities' land area is considered vacant, with approximately 4 percent of city addresses unoccupied.
- Most vacant parcels are "small, odd-shaped, and disconnected," making them difficult to redevelop.
- Disinvestment and a lack of capital reinvestment are primary reasons for abandoned buildings and vacancies.
- Obsolete real estate is becoming a growing challenge: "The spread of obsolete real estate may have displaced brownfield properties as a main driver of vacant land." [27]

In a "heat-map" study of representative US cities conducted for this paper, Newman and his colleague Ryun Jung Lee determined that small, hard-to-develop parcels constitute about one-third to one-half of the vacant land inventory in US cities. A look at three cities, each with different profiles—Chicago, Dayton, and Minneapolis—reveals the extent of the challenge and the opportunity. Chicago's remnant parcels represent more than half of its

BY THE NUMBERS: OPPORTUNITIES TO REPURPOSE U.S. REAL ESTATE

✓ 17 percent vacant land across large cities

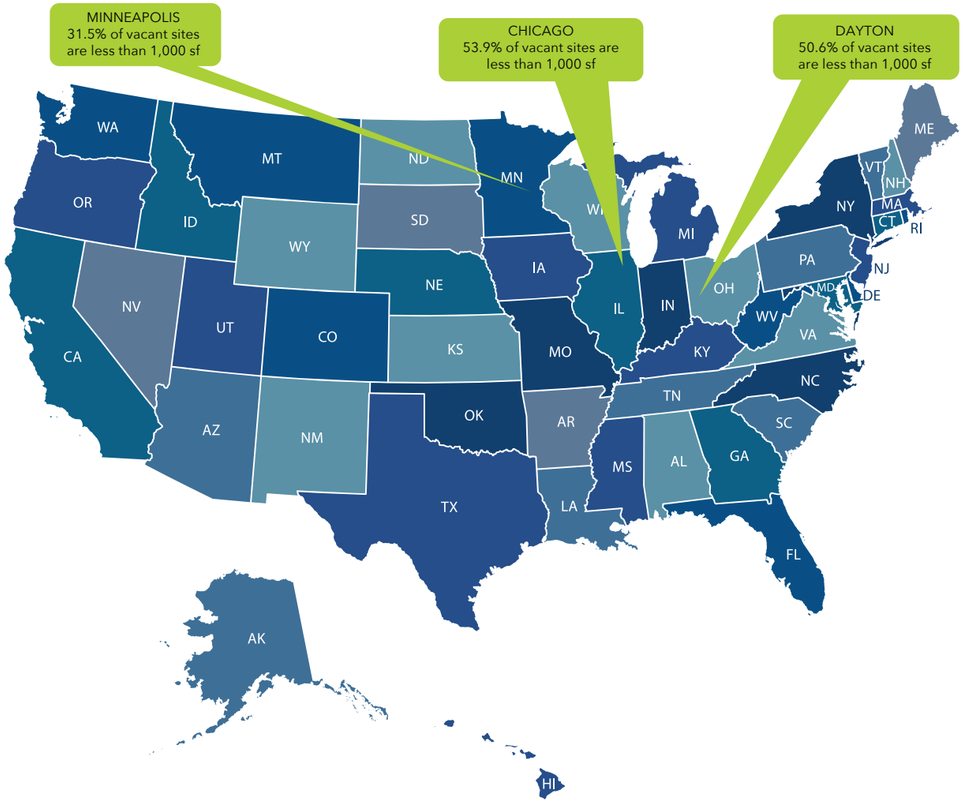
✓ 4 percent of city addresses vacant

✓ Nearly 1 trillion square feet of obsolete suburban office space

✓ 25 percent of US shopping malls slated to close within next 5 years

✓ 5.3 percent industrial vacancy rate—a 17-year low [28]

[27] Newman, Galen, et al, "A current inventory of vacant urban land in America," Journal of Urban Design,Vol. 21, Issue 3, April 2016, pages 302-319.
[28] CNBC, "US warehouses are costly and hard to come by," June 14, 2017.



Small, hard-to-develop sites constitute one-third to one-half of the vacant land inventory in US cities.
Source: Galen Newman and Ryun Jung Lee, Texas A&M University

vacant land. In Dayton, nearly 51 percent of vacant sites are less than 1,000 square feet. Of Minneapolis's vacant land, 30 percent of the sites are 1,000 square feet or smaller.

Potential Solution for Urban Blight

The oversupply of such nonproductive space represents a major challenge for city officials and economic developers today. It contributes to urban blight. It can depress land prices, property values and tax revenues, increase abandonment, decrease employment rates, sales, investments and vitality. And it can result in loss of residential, commercial and business activities.[29]

According to Newman, providing a way to redevelop harder-to-build sites—small, awkwardly shaped remnant parcels—for new uses would mean real progress towards solving this problem.

"The entire notion of designing buildings that slide into narrow and unusable slivers of land and can accommodate a mix of uses absolutely could help stimulate new economic activity," Newman says. It could contribute to revitalizing cities—or parts of cities—that may be losing population and reinvestment.

Now more than ever, land in densely populated areas is being eyed for industrial warehouse development.

To truly maximize the potential, however, developers would likely need to aggregate several adjacent small sites for lot-line-to-lot-line development. And here's where the obstacles arise. "While many of these small, vacant parcels may be beside one another, they cannot be necessarily combined," Newman says. The reason: each parcel is platted separately and may have a different owner. "To combine them would entail purchasing each parcel by one owner and re-platting the entire parcel data set for property boundaries."

Rather than seeing these obstacles as insurmountable, this unique confluence of events—the promise of revitalization and the need for more urban storage space—creates a window for innovation and dialogue. City planners might consider revisiting their zoning codes and reducing the red tape associated with aggregating land. Regional, state, and local officials might revise their incentives regimes to encourage redevelopment. And corporate users of urban industrial space might commit to local training and hiring in sections of cities characterized by high unemployment, thereby triggering additional economic growth.

Building Up, Not Out: Air Rights as the New Warehouse Development Frontier

Third-party logistics providers like ProLogis are already eyeing land in densely populated areas for industrial warehouse development. But with demand growing and limited availability of large, industrial-zoned parcels in desirable locations, designers of warehouse space are beginning to look upward, rather than outward. They are changing their approach so they can take advantage of airspace to build vertical fulfillment centers that fit into the cityscape.

In April 2017, ProLogis broke ground on the first such facility in its own portfolio—a three-story, 589,615-square-foot fulfillment center in South Seattle. The project, Georgetown Crossroads, is a first-of-a-kind in the United States—a highly visible, Class A facility featuring ramps for truck access to second-floor loading docks. A freight elevator will link the third floor to ground floor loading docks. The company reports that the new paradigm was necessary because of two factors: Consumers are increasingly coming to expect rapid delivery of online orders, and transportation costs are rising. In response, retailers and manufacturers alike are looking to move fulfilment operations closer to population centers. With inner city vacancy rates at historic lows, however, finding available square footage is a challenge—leading to the change in the company's design approach. [30]

This example brings into focus the challenge for developers, owners, and users of warehouse space. Now, more than ever, land in densely populated areas is being eyed for industrial warehouse development. Repurposing narrow slivers of hard-to-develop urban

[29] Schilling & Logan, "Greening the rust belt: A green infrastructure model for right sizing America's shrinking cities," Journal of the American Planning Association, 2008, Vol. 74, pages 451-466.

[30] ProLogis, "Rising to the Challenge with the First U.S. Multistory Warehouse," 2017.

land into multiple vertical, hyperlocal warehouses as proposed by the DesignFlex team could open up a world of options, even as removing stubborn little pockets of urban blight represents a real win for cities.

ASRS as 24/7 Public Performance Art

The mechanics of massive industrial operations have long been the source of artistic inspiration. There is a line of beauty that runs through the elegant design and sophisticated engineering of all industrial machinery. The genius of the urban vertical warehouse concept lies in opening up that line of beauty for all to see—the cool runnings of a fully automated, three-aisle ASRS system, lit by LED lights that can change color with the touch of a button. The opportunities for this are boundless—as a placemaking public space; as a way to monetize the façade and use it as a commercial billboard; as a way to declare pride in the city or welcome a special event to town. Such a structure contributes to a sense of place, giving personality and character to a community. "What's so exciting is that by taking the ugly warehouses that cities have hated and creating a totally different archetype, we are making the city street love it," Heitman says.

Adaptive Reuse of Aging Commercial Space

As vacancy rates for aging office complexes and older retail centers rise, revitalizing these facilities as mixed-use, live-work-play communities—including a warehouse and fulfillment component—becomes more attractive. With an upscale design ethos, internal, less desirable square footage becomes flexible space for 3-D printer farms and microfactories, along with warehousing capabilities and storage for advanced raw materials used in additive manufacturing. It's all linked via mass transit skyways and underground freight hyperloops to replenish hyperlocal urban centers.

> **"What's so exciting is that by taking the ugly warehouses that cities have hated and creating a totally different archetype, we are making the city street love it."**
>
> **–Karl Heitman,** Design Team co-lead and president, Heitman Architects

These properties are available and ripe for redevelopment. Between 500 billion and 1 trillion square feet of America's suburban office space is obsolete, with a growing vacancy rate, according to Newmark Knight Frank's Greg Leisch. "Until now the write-down needed to re-purpose suburban office campuses for warehouse was so high as to not be cost-effective," he says. "This is slowly beginning to change as builders realize that these offices are so obsolete that they need to do something drastic so they can at least access the ground value." Many are already looking at mixed-use projects that include residential and retail components.

Once-highly coveted inner city offices are not immune to this obsolescence: Take 666 Fifth Avenue, a property in the heart of New York City owned by the Kushner Real Estate Group. The cost to reconfigure the existing structure has soared to the point where one broker recently told Vanity Fair magazine that the site "would be worth a lot more if it was just dirt."[31]

Here's an idea for the Kushners and others similarly stuck: Consider a flexible repurposing, using the hybrid, hyperlocal model proposed by the DesignFlex team.

It's an idea whose time is coming, experts say. "I believe we will start to see urban properties being snapped up for mixed-use projects that also include warehouse, especially as companies like Amazon and WalMart get even more serious about two-hour delivery windows," notes Leisch. "The only way to do this is to move goods closer to end users." Such projects will likely include flexible space that can accommodate online order pickup and drop-off.

Revitalizing Failing Shopping Malls

Obsolete or failing retail centers with vast parking structures are a problem for municipalities everywhere. The distribution network of the future gives these sites a refresh by bringing in a mix of uses. Some retail might remain, along with e-commerce last-mile storage, pickup and return. Other activities could create excitement and add foot traffic, such as restaurants, "maker space" for small-scale personalized additive manufacturing, learning centers—and even a residential component.

Already, the failure rate of retail centers is raising eyebrows—and leading to the possibility of change. "If the alternative is an antiquated or failing center in a municipality, zoning authorities and their communities will eventually be compelled to consider zoning changes allowing small-scale distribution facilities at current retail-zoned sites or face the prospects of a blighted center, lost jobs and tax revenue," write Fitch analysts Kellie Geressy-Nilsen and Christopher G. Pappas in Chain Store Age.[32]

> **"Until now the write-down needed to re-purpose suburban office campuses for warehouse was so high as to not be cost-effective. This is slowly beginning to change as builders realize that these offices are so obsolete that they need to do something drastic so they can at least access the ground value."**
>
> **—Greg Leisch,** Newmark Knight Frank

Planning Tools and Policy Changes to Accommodate a Wider Range of Uses

Localities slated to lose important corporate citizens or faced with too many empty storefronts are indicating interest in redevelopment opportunities that would help promote their own smart-growth strategies. Take Alexandria, a small city in Northern Virginia located just across the Potomac River from Washington, DC. Once known as the Association Capital of the United States for the number of industry and services association headquarters, it has seen its office vacancy rates creep up in recent

[31] Levin, Bess, "Jared Kushner's Family is Screwed and It's All Boy Wonder's Fault," Vanity Fair, October 16, 2017.
[32] Kellie Geressy-Nilsen and Christopher G. Pappas, "Location, Location, Location' still applies, possibly now more than ever," Chain Store Age, May 30, 2017.



Empty parking lots and underused retail centers dot the global suburban landscape.

years. After a study commissioned by the city found that conversion of old offices into a mix of residential, retail and other uses can trigger significant new private investment, officials are taking steps to encourage such plans. They are considering new policies and incentives—namely real estate tax credits for capital investments in aging commercial properties—to support proposals that break up large blocks of empty and aging commercial space.[33]

Forty miles southwest of Alexandria, officials in Stafford County, Virginia, are amending their zoning code to allow for a dense mix of retail and residential uses on land formerly reserved for corporate campuses. County officials in this exurban community—home to a major US military base and many defense contractors—are rethinking their approach as way to keep long-time employers happy, reduce commuter traffic jams, and encourage new population growth. "The desire was to make these places more vibrant at all hours and to accommodate the lifestyles of younger workers who want to live and work in more urban, walkable environments by putting housing and retail nearby," explains Jeff Harvey, Stafford County director of planning and zoning. He expects that future development on these sites might include restaurants, small retail showrooms and warehouse capabilities to accommodate e-commerce fulfillment and returns.

Obstacles to Overcome

As these shifts take place, companies trying to optimize their supply chain and distribution will face several critical challenges, including striking the balance between efficiency and cost-effectiveness from point of manufacture to last-meter delivery. This will involve a highly complex calculus to determine optimal locations and delivery modes.

Other challenges include inventory management. "You will have to ensure that the right product is close enough to the customer so you can meet the very short timeline window," notes Winkenbach. For commoditized products it will be comparatively simple to determine location and stocking levels, as the IoT will instantly generate data on who is purchasing what and at what frequency. "Optimal inventory management for non-commoditized products will be far more complicated," he says.

It's likely that new cost-and-location modeling software will collect and analyze the massive amounts of data gathered through the IoT to help companies determine optimal stocking levels at various facilities. These tools include the ability to aggregate

[33]Niebauer, Michael, "Massive Office to Residential Conversion Planned," Washington Business Journal, May 19, 2017; Alexandria City Government, "Fiscal Impact of New Development" presentation, May 2, 2017.

and analyze online ordering data to understand more about which buildings consume what kinds of products and at what rate. Sophisticated algorithms can help identify optimal inventory levels at the various distribution centers in an individual company's network.

Companies also will have to resolve such issues as how to determine SKUs to be eliminated and replaced with digitally manufactured customized goods; what still gets produced in a conventional manufacturing plant; and how to configure internal spaces for maximum flexibility and rapid change-outs.

The bottom line here is that the twentieth-century construct of "better-faster-cheaper" hasn't changed. What has changed is what it means to be better, faster, and cheaper—and therein lies the distribution challenge of the future. By 2030, there will be clear winners and losers in the race to achieve the optimal balance.

Areas for Future Study

As the team moved forward with its work and identified the full array of disruptions taking place, it became clear that some related issues requiring exploration fell outside the scope of this paper. Understanding more about these areas will contribute to the global industrial real estate knowledge base.

Additional study could help provide more comprehensive guidance as managers of industrial real estate portfolios hammer out their short-, medium-, and long-term strategies. Further exploration is recommended on the following:

- Zoning codes: Changes to accommodate flexibility as uses change
- Identification of future warehouse needs: Will the need for the mega-warehouse disappear entirely? Will there be a shift toward holding more properties, each with smaller footprints?
- Incentives to encourage redevelopment of remnant parcels and obsolete office space
- Approaches to strengthen fiber-optic networks
- Energy investments to enable power redundancy
- Demographic trends as the millennial generation ages: If the urban trend reverses itself, can the distribution network accommodate the shift?
- Transformational strategies to create smart, connected cities
- Financing next-generation transportation infrastructure

"We are in a truly exciting era of reimagining our global supply chain. Distribution centers will become locally sourced factories linking producers and consumers in a closed-loop economy."

—Karl Heitman, Design Team co-lead and president, Heitman Architects

FINAL THOUGHTS

It bears mentioning what many readers of this paper inherently understand: No two industrial supply chains are the same. What's right for bulk chemicals logistics and warehousing isn't going to work for packaged T-shirts or for kitchen sinks. Thus, the DesignFlex design team faced an inherent challenge in identifying a path forward that would address the future uncertainties across the sectors. The concepts proposed are not intended as a single, one-size-fits-all solution. Rather, the idea is to start a conversation—to give holders of industrial real estate portfolios new ways of looking at this changing landscape. Grounded in reality but imaginative in scope, these are innovative suggestions that might not have been considered otherwise.

Notes Design Team lead architect Karl Heitman: "We are in a truly exciting era of reimagining our global supply chain. Distribution centers will become locally sourced factories linking producers and consumers in a closed-loop economy."

Adapting to the transformation already underway and preparing for the future represents an enormous—and very expensive—task that extends far beyond the mechanics of how to design and build a better warehouse. This will require close collaboration and partnership. It means bringing to the table industry representatives, commercial real estate developers, technology companies, infrastructure providers, economic developers and local officials alike, to identify approaches that incorporate hyperefficient supply-chain and distribution networks as part of more comprehensive smart city strategies. It also means new public-private partnerships to finance the modernization of transportation and power grids and the development of smart communities that are equipped to accommodate the shifting paradigms.

While not every concept identified in the paper applies across the board, there is something here for everyone to consider, as the disruptive forces that are already altering the distribution universe gain momentum and permanently change the status quo. As with earlier DesignFlex research, the single most important conclusion is this: An effective, future-proof industrial real estate strategy will depend on flexibility and upfront investment in construction techniques and building materials that enable rapid changeout and re-configuration, as these disruptive and transformational tides roll in.

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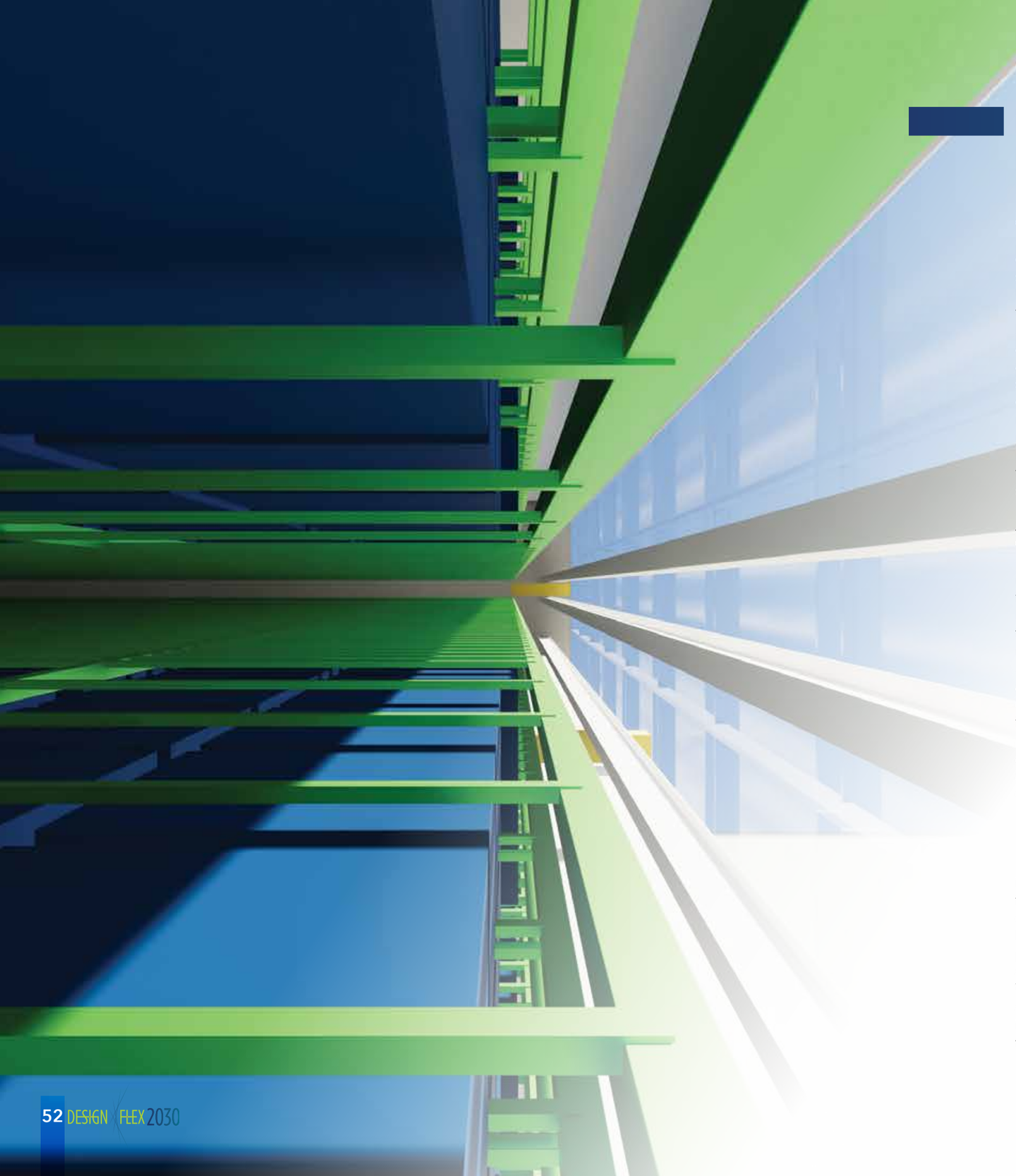
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Andy brings more than 25 years of multifaceted supply chain, logistics, operations, finance, and supplier management expertise. Having led finance, planning, engineering, transportation, sourcing, distribution, and manufacturing operations, he brings a unique perspective to aligning operational and financial reporting requirements. Andy's expertise includes inventory management, freight, service management, business analysis, procurement, process design and implementation, asset rationalization, acquisition integration, and corporate real estate management.

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With over 20 years of experience in the industrial space, Phil spearheads operations-focused initiatives that help fast-paced organizations improve their business practices. Phil has directed and executed challenging programs for industrial companies in the automotive, medical device, and food sectors. With this diverse experience, he is adept at understanding the changing needs of industrial-sector companies and applying lean thinking to generate operational efficiencies.

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Karl Heitman, AIA

Founder and president of Heitman Architects, Karl brings 40 years of experience in the design of over 40 million square feet of corporate/industrial buildings. Karl currently leads the firm as design principal on a diverse range of manufacturing projects, corporate consolidations, and redevelopment projects. He is an active member of the American Institute of Architects, Design Futures Council, and the US Green Building Council.

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Paul has been with the firm for 10 years and serves as the company's director of marketing and new business development. With a bachelor's degree in fine arts from SAIC, the School of the Art Institute of Chicago, and graduate architectural studies at SCI-ARC, Southern California Institute of Architecture, and IIT, Illinois Institute of Technology, Paul brings a creative approach to conceptual research. Paul is also active in Chicagoland community and economic development. He serves as president of the Golden Corridor MakerSpace, a nonprofit dedicated to inspiring and supporting young people and businesses to "make," by democratizing access to design and fabrication tools.

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