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Moving Parts: Modular Architecture in a Flat World

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There is an urgent need for a transformation in the way we design and build our cities that will bring down costs, and that will attract people to live in dense transit-based urban neighborhoods. A specific proposal for a new type of modular building system is essential, an approach to mass-customized modular architecture that can be manufactured and marketed on a global scale, based on the re-design of the standard shipping container as a purpose-engineered chassis for mid- to high-rise buildings. The ramifications of a globally distributed system of modular building are far-reaching, and will engender new modes of project delivery and new relationships among architects, planners, developers, builders and a nascent global modular manufacturing industry.

Housing Every Two Seconds

By the time you finish reading this sentence, the world's urban population will have grown by one new household. And as you pause for a moment to consider that, another household will have been added… pause…and another. The world's population is not only growing, it is urbanizing… rapidly. New urban households are forming eighteen times faster than rural households. In 2010, for the first time, the proportion of the world's population living in a city passed the 50% mark, and urban population will continue grow into the foreseeable future, with the figure rising to 60% by 2030 (citymayors.com, 2012). By 2050, the world's urban population is expected to increase by 2.5 billion inhabitants, according to a United Nations report (United Nations, 2014). At roughly five persons per household (Bongarts, 2001), that's a total of 500 million new households, which of course also means that the same number of dwelling units need to be constructed to keep up with household formation. If you do the arithmetic, that comes to a need for 275,000 dwelling units every week for the next 35 years. Equally staggering, it has been estimated that in 10 years, by 2025, there will be 440 million *existing* urban dwellings that are substandard, not fit for a healthy, dignified existence (Woetzl, Mischke & Ram, 2014). Virtually every breath you take marks the need to add one urban dwelling unit somewhere on the face of the globe, most likely in a developing country.

The wherewithal to purchase a car is considered the benchmark of entry into the middle class, and roughly seventy developing countries, altogether containing about 4 billion people, are poised to see rapid increases in car ownership in the years ahead (Shimelse & Dadush, 2012). The global rise in car ownership, while marking economic improvement for tens of millions of people a year, is at the same time an ominous trend, because with widespread automobile ownership comes the tendency towards American-style sprawl. Land use patterns in the developing world increasingly resemble our own, with urban surface area worldwide increasing at twice the rate of urban populations (Seto & Guneralp, 2012). On a global scale a growing and urbanizing middle class is buying cars and using them to live on the outskirts, away from dense city cores, a trend that can be reversed only with planning policies that encourage density. Such policies include investment in mass transit; compact land use / density tied to transit (TOD); public safety; in water, sanitation, electrification, and other infrastructure; but without *safe, economical, high-quality multi-story dwellings that can be built at a rate that keeps pace with urban*

population growth, the trend towards sprawl will continue unabated. The land use problem is inextricable from the problem of construction economics.

Prefabrication and modular construction have seen a recent resurgence of interest as a means to "crack the code" of construction costs. In theory, modular construction could be a solution to the growing worldwide need for housing, and for multi-story housing in particular, offering a means to achieve quantity and affordable quality. Promising in theory, that is, but perhaps not yet ready for prime time, at least not without some fresh thinking.

The global market for prefabricated housing is forecast to reach 829,000 units by 2017. At an annually compounded 4.4 percent growth rate the global market will reach 3,432,978 units (DRM Investments, 2014). While this may sound like a lot of units, it is in fact a meager output that is but a small fraction of one percent of the anticipated need for nearly a billion new and replacement urban housing units worldwide. The existing modular industry is simply not equipped to respond in any meaningful way.

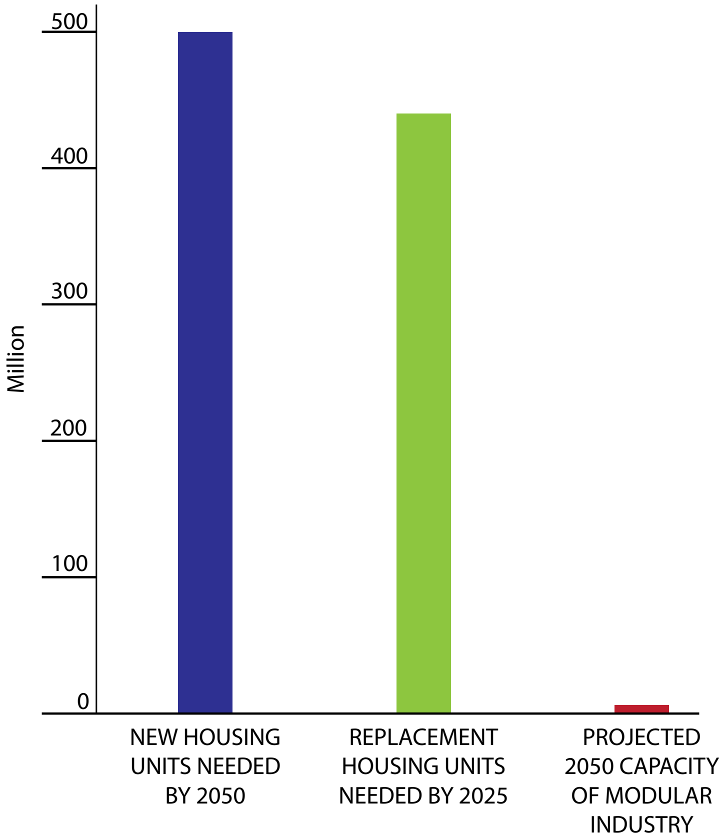
The authors propose a categorically different approach to mass-customized modular architecture that can be manufactured and marketed on a global scale. The proposal will fundamentally change how cities are built, transforming design and construction along the lines of the technology sector, with ramifications that will be felt by architects, planners, developers, builders, and not least of all, the consumers of buildings – anyone, in other words, who buys or rents an urban dwelling.

Drawing the Energy Boundary

Land use patterns are the single most important factor affecting energy consumption and greenhouse gas emissions. Think of a pyramid representing energy savings and the dollar cost of achieving those savings. At the top of the pyramid are the technological fixes like solar panels, fuel cells, and so on. In the middle there are building and site specific design strategies that use passive energy saving principles. Down at the broad base of the pyramid is land use. Simply by building cities, as opposed to suburbs – regardless of how energy efficiently you build – you get the greatest energy savings and greenhouse gas reductions.

Opposite: American-style suburban subdivision, as pioneered by William J. Levitt. Low-cost production stick-frame housing developed on inexpensive tracts. Source: FXFOWLE

Top: Traffic congestion. In the ten most congested American cities drivers spent an average of 42 hours a year sitting in traffic. Source: FXFOWLE



Left: The anticipated demand for urban housing over the next thirty-five years contrasted with the projected capacity of the modular industry as presently organized. (Note that the projected capacity is predominantly single-family manufactured housing, or trailers in common parlance). Source: FXFOWLE

Opposite Top & Bottom: The building site contrasted with an automotive assembly line. Despite modern materials and methods, the building site in its essential aspects has not changed for thousands of years. Source: FXFOWLE

The Jonathan Rose Company, a real-estate firm that specializes in environmentally responsible development, did a study in 2011 that compared household energy consumption between urban and suburban patterns of land use. The Rose Company's findings challenge our received ideas about energy efficiency. They discovered that when you step back and consider housing density, housing type (single family versus multi-family), and proximity to energy efficient public transportation, the gains in energy efficiency that are achieved outshine the gains from middle- and top-of-the pyramid technologies. For example, according to Rose, a family living in a conventional multi-story apartment building – *constructed without energy efficient features* – in a neighborhood with access to transit consumes forty percent less energy than a suburban house built with features like high efficiency heating systems, low wattage light fixtures, airtight and well-insulated walls, and the like. Yes, energy efficient construction still matters, and by bringing that urban multi-story apartment building up to stringent energy standards, an additional sixteen percent gain can be achieved, for a fifty-six percent reduction in total compared to an equally efficient house in the suburbs (Rose, 2011).

In contrast, consider the unintended consequences when energy savings are first sought at the top of the pyramid – the technological fixes – rather than at the base. Amplifying on Rose in a 2012 study the NRDC (Bacchus & Goldstein, 2011) showed how energy efficiency can be perversely undermined by policies that promote solar panels. The sloped roof of a suburban house standing by itself on a plot of land is the ideal mounting position (assuming it faces more or less south) for solar panels. The land use patterns that are ideal for rooftop photovoltaics, the NRDC found, resemble nothing other than Sunbelt sprawl!

The economist Edward L. Glaeser has studied the comparative energy use of U.S. cities and suburbs, tallying the impacts of heating fuel, electrical consumption, driving, and public transportation, and finds convincing evidence – confirming Rose – that dense, vertical cities are far more energy efficient than their suburban counterparts. Glaeser's findings also take into account that much of the housing stock in cities is old, with poor insulation, drafty windows, and inefficient heating systems, whereas suburban housing stock tends to be newer and better insulated. Glaeser shows that even with those very inefficient buildings in the mix, for example, "an average New York City resident emits 4,462 pounds less CO_2 annually than an average New York suburbanite" (Glaeser, 2009). Given that Glaeser's numbers are based on highly inefficient old buildings, it seems safe to say that CO_2 reductions for new, energy efficient urban buildings in a city like New York would far surpass a zero net energy suburban house with rooftop solar panels.

No doubt about it: dense development in city cores is energy efficient, and an economical high-rise modular system as an urban building block is far more effective in reducing greenhouse gas emissions than a landscape of suburban rooftops covered with solar panels.

Moving Parts

The search for a better way to organize building construction, on a par with the automotive, aerospace and shipbuilding industries is a mythic quest of modern architecture. The modernist pioneers of the

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early 20th century envisioned new industrial technologies in the hands of architects that would be a solution to the housing problems of their era. Since that time there have been innumerable attempts to marry architecture and manufacturing, some succeeding as polemic, and some succeeding as prototype, but none to date has succeeded to any great degree in transforming building culture.

In the modernist spirit, architects Stephen Kieran and James Timberlake make a cogent and compelling case for transforming the way we build in their book "Re-fabricating Architecture" (Keiran & Timberlake, 2004), in which they draw a sharp contrast between the architect and the process engineer. In their argument, the former is wedded to anachronistic notions about art, and the latter dedicated to efficiency and "commodity". Architecture is fragmented, where industry is integrated. The industrial process engineer designs the relationships among the many parts and participants so that they merge seamlessly in a complex endeavor. The architect, on the other hand, is relegated to the comparatively narrow task of designing of a building.

Keiran and Timberlake study modern supply chain manufacturing methods, and compare those methods with building construction.   Today, OEM's (Original Equipment Manufacturers) source myriad components and subcomponents from a global network of suppliers. Very large objects, like jumbo jets and ships, are assembled in prefabricated "chunks" fitted out with systems and finishes. Only at the final assembly stage are the chunks, which may be entire sections of fuselage, joined together and systems stitched into a complete whole.

But the domain of process control stops at the factory or shipyard gate. Process engineering provides a method to control the manufacture of a large discreet object assembled under one roof. So far, so good, but Keiran and Timberlake don't follow their logic all the way through when it comes to industrializing the building process. The vexing problem of assembling buildings from modules, as opposed to a jetliner, is that once the building module exits the factory *it is no longer under the control of the process engineer*. The slow, cumbersome, and expensive way in which building modules are traditionally moved from factory to building site remains the weak link in the chain.

Here is the crux of the matter: the problem of transportation logistics in modular building construction is the problem of modular building construction. Questions of factory capacity, growth potential, innovation and R&D, all stem from transportation.

Supply chains in a global economy are dependent on global transportation. The incumbent modular manufacturers – which are without exception relatively small companies – have imprisoned themselves in what we might call the *transportation fallacy*. They strive to build the largest possible modules, in the belief that economy comes from having the fewest units to roll down the highway and crane onto a foundation, and the fewest number of joints to close up and finish in the field. As an unintended consequence of this commitment to super-size modules, the incumbents have burdened themselves with high transportation costs owing to the need for escort cars, planned routes, overnight accommodations, fuel, special permits, insurance, as well as regulatory limitations on hours when modules can be transported into urban areas. As a further consequence the incumbents are unable to compete with conventional construction beyond about a 200 mile radius (Smith, 2011), and even within that limited range they rarely compete on cost savings – instead, they compete on time savings alone. The combination of high overhead, high local labor rates and limited market opportunity makes these companies vulnerable to the ups and downs of the business cycle, and reluctant to invest in plant, equipment, and R&D. Like stunted trees on an exposed mountainside they expend all their resources on survival and cannot grow.

Even the time saving argument starts to unravel when it comes to larger buildings, say a typical urban high-rise. Part of the idea behind saving time in modular construction is that you can be manufacturing modules while foundations are being poured, so that modules start arriving at the site for craning as soon as the foundation is ready. However, once foundations are done the rate at which modules can be produced in the factory has to match the speed with which the crane can operate, or those time savings will quickly evaporate. The incumbent manufacturers, with small facilities that don't exceed a couple of hundred thousand square feet, cannot produce at a rate much faster than three modules a day. This is because production modeled on the traditional division of building trades rather than on supply chains. As the following example will demonstrate, at this rate of production there is a natural limit on time savings for larger scale buildings.

A single crane hoisting large, heavy modules weighing as much as 80,000 pounds can stack up to twelve modules a day, or four times the factory production rate. What happens if a large building – let's say a tower on the order of 500,000 square feet – is being manufactured? Production capacity – at one-quarter the rate of crane capacity – starts falling behind as soon as foundations are completed. Let's assume a fairly typical twelve by forty-foot module, comprising 480 square feet. Allowing 6 months for foundations, at the upper rate of three modules a day 396 modules or about 190,000 square feet are in storage ready to start stacking when foundations are done (requiring about eight acres of storage space). The 645 modules comprising the remaining 310,000 square feet will take another ten months to manufacture, during which that costly crane and operating engineer, rented by the day, is working at 30 to 40 percent efficiency. Add another four to six months of hook-ups and final finishing after craning is finally done and the construction time comes to a total of twenty to twenty-two months – which is comparable to a conventionally constructed building. The potential was there to shorten that time by seven to eight months, but the limiting factor turns out to be the rate of factory production.

Opposite: A typical oversize modular load being trucked. In addition to being costly to transport, these loads have difficulty navigating tight urban streets. Source: FXFOWLE

Top: A two-hundred mile radius centered on New York City, illustrating the transportation range for conventional oversized modules. Source: FXFOWLE

Bottom: A typical intermodal container port. The shipping container is equipped with standard corner fittings designed for automated crane operation. Containers are transferred seamlessly from ship to truck or train flatcar. RFID technology monitors container locations anywhere in the world in real time. Source: FXFOWLE

Now consider this from a business point of view. The factory that undertakes a 500,000 square-foot building will be tied up for a year-and-a-half on that one project. All other sales opportunities must be passed up. By the time the manufacturer is finally ready to accept a new order customers will have been driven to the competition. To maintain marketing and sales momentum, project turn-around cannot be much more than just a few months. Another limiting factor is that large-scale projects require large-scale markets.

Transportation is not only *the* problem that must be solved, but it is the problem that must be solved *first*, before a scalable system for manufacturing modular buildings capable of mass-production – ideally of mass customization – will come to fruition. And the solution, which has been right in front of us for more than half-century, derives from the standard ISO shipping container. The shipping container, a cheaply transported modular structure, is the basis of our modern global supply chain, moving seamlessly by ship, rail and highway, as if carried along on a giant globe-strapping conveyor belt.

Why can't the incumbent manufacturers just speed up production or build bigger factories? Or more decentralized factories? Why do global supply chains matter? The answers have to do with the difference between simply moving the construction trades indoors, which is what the incumbents do, and transforming the modular industry along the lines of other advanced manufacturing sectors. With supply chains, myriad components are manufactured simultaneously by specialized suppliers. Components converge at an assembly facility, where building modules are rapidly put together on a moving line. Supply chains require economies of scale and standardization. The hide-bound incumbent manufacturers will never achieve scale, and don't (can't) think in terms of standardization.

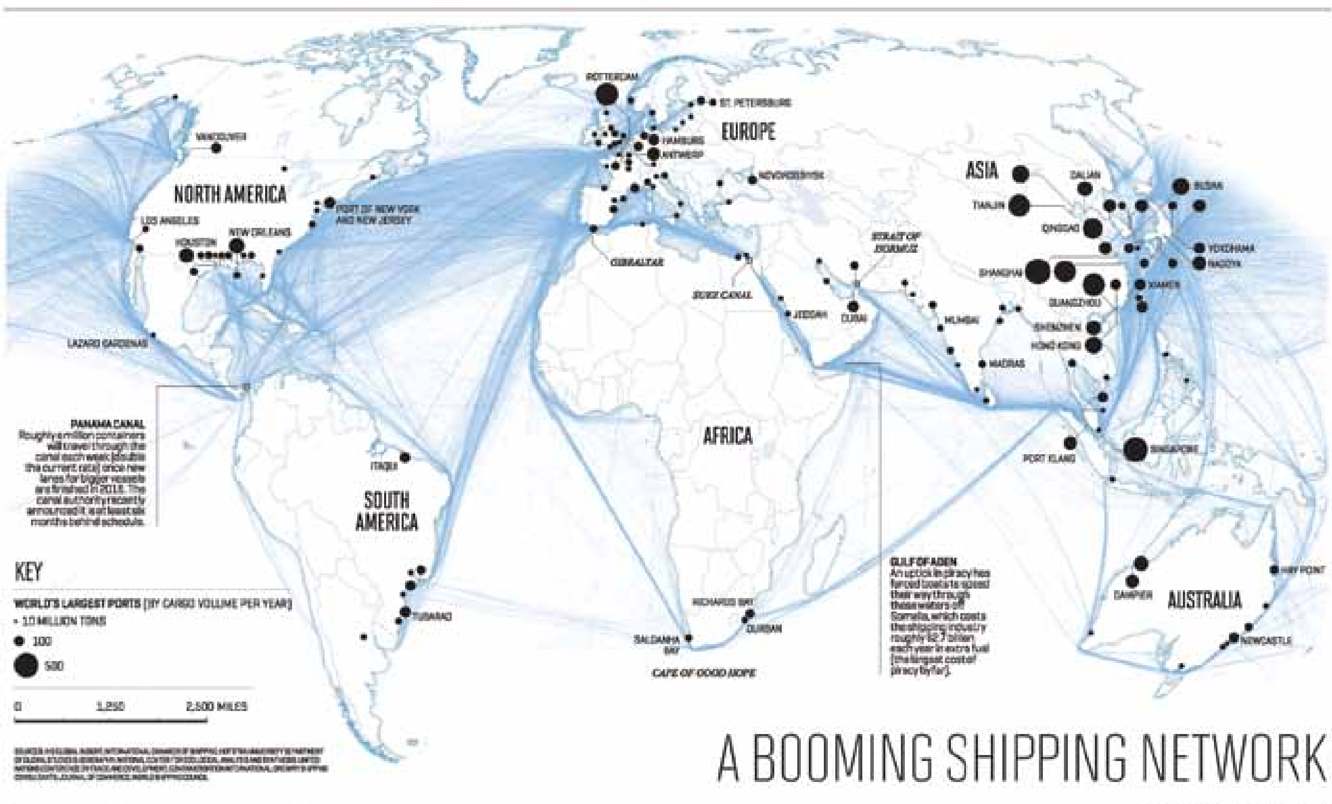
If there is to be a response to the need for multi-story urban housing on a meaningful scale, then modular needs to go global.

But matching a crane rate of twelve modules a day is far too limited a goal. In 1948, the Lustron Corporation – the last serious effort at industrial scale production – had designed and tooled up a 1 million square-foot former aircraft factory with a vertically integrated production capacity of 400 houses a day, or the equivalent of 1,200 modules. One high-rise tower *a day*. That's scale.

Shipping Containers Transformed

Actual shipping containers, as it turns out, have significant technical limitations when it comes to building construction. A realistic look at the problem of obtaining used shipping containers will make evident how unfeasible it is to use them for any but the smallest buildings. To get to a significant scale of operations would entail the recovery of hundreds of thousands of containers a year. In this scenario, the ability to recover and reprocess used shipping containers quickly becomes another scale-limiting factor. Even if there were a way to recycle in quantity there are problems with structural soundness, contaminants such as bituminous waterproofing and pesticides, and combustible plywood floors that will not meet code for fireproof construction.

Further, much of the value-added material in a shipping container must be thrown away. The freight doors on one end of the container are of no use in building



Nicolas Rapp for Fortune Magazine

Opposite: Intermodal shipping lanes. Every year, roughly 25 million containers are moved on the intermodal transportation system. Source: FXFOWLE

Top: The specially designed Lustron tractor-trailer. Lustron's plant was laid out so that the trailer could move along the factory assembly line for loading in the reverse order of assembly at the site. Source: FXFOWLE

Bottom: The shipping container is encumbered by numerous features that are disadvantageous for building construction. Stripped down to its essentials – standard ISO conforming dimensions and corner nodes – can be re-engineered to be optimized as a building module. Source: FXFOWLE

construction. Much of the corrugated steel siding must be cut away and sent to the scrap yard in order to make a modular system that can be expanded spatially – we don't want rooms to be limited to an eight-foot width – so the frame of a standard shipping container then becomes too weak and has to have steel reinforcement welded to it. Costs add up, steel is wasted, and the slow process of converting a shipping container to a building module further limits the scale of operations.

If scale is the objective, then what's needed is a module that can be cheaply transported like a shipping container but which is engineered from the get-go to be optimized for mid- and high-rise building construction. Such a module would need to meet ISO's dimension standards, and would need to be fitted out

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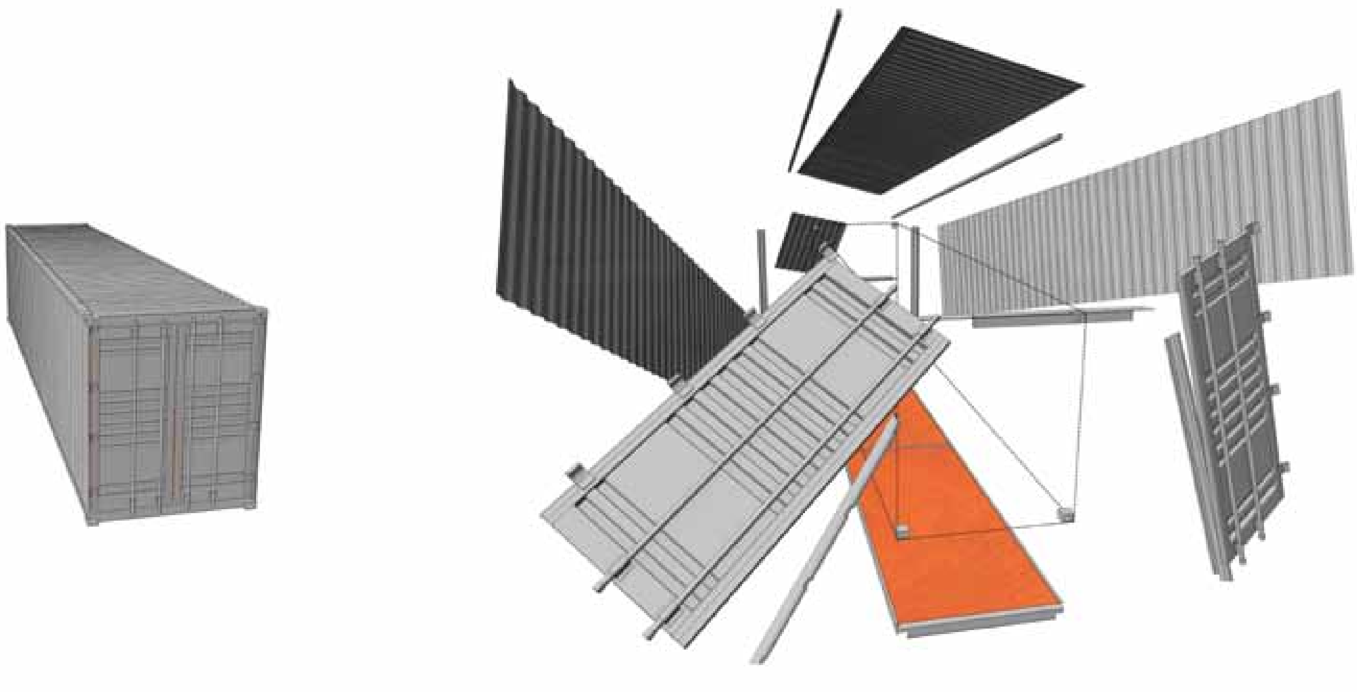
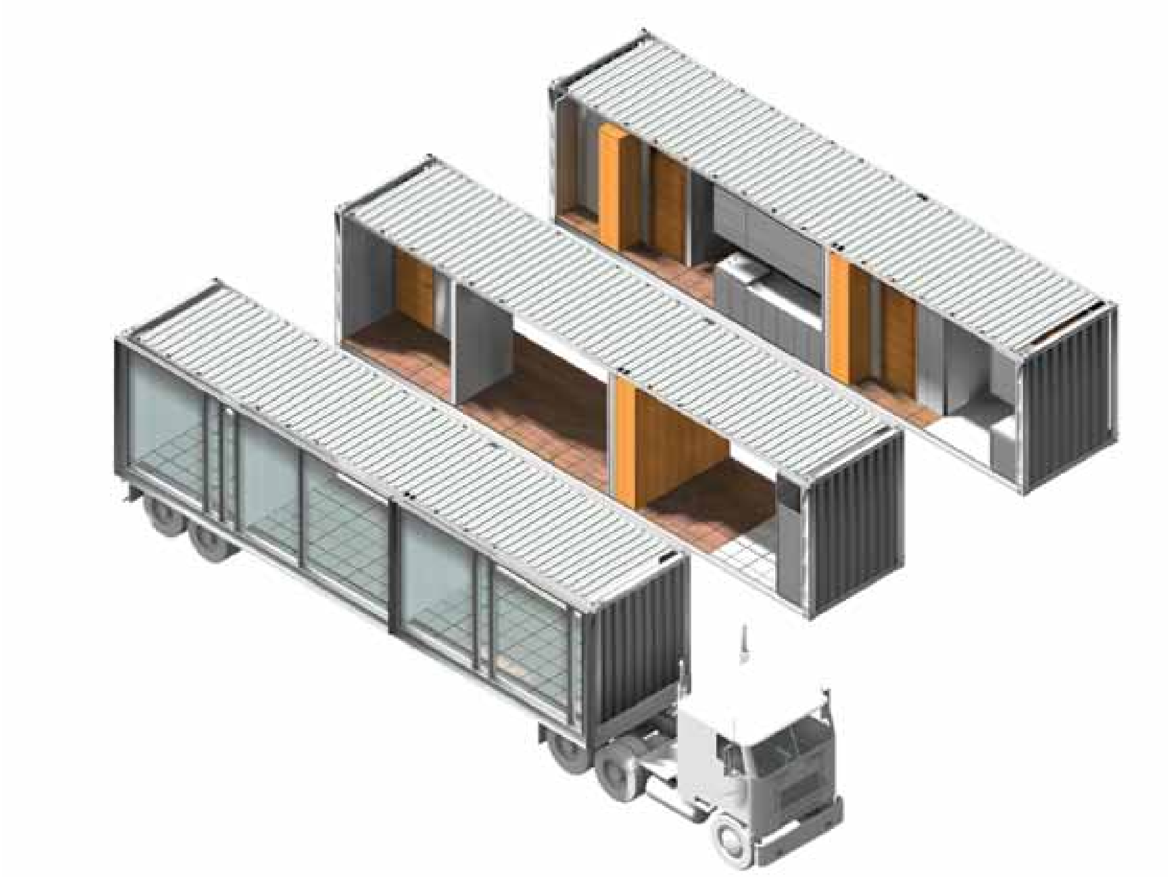




with the eight steel corner nodes which enable automated intermodal handling. We'll call that new type of building module a Volumetric Unit of Construction, or VUC, to clearly distinguish it from a shipping container.

With such a system fully engineered and proven out, a continual stream of variations, accessories, and add-ons can be developed to fit on the basic VUC chassis, enabling design flexibility and choice – not unlike an iPhone, in which hundreds of thousands of apps have been developed to work on Apple's operating system. Like apps, the plug-and-play accessories for the VUC – balconies, shading systems, secondary façades, etc. – could be developed by third-parties: building product manufacturers, architects and industrial designers, or anyone, for that matter, who has an idea and the technical wherewithal to work it out and coordinate details with the VUC manufacturer. The catalog, fueled by internet-based commerce, would become a globally shared platform for collaborative design. With a modular industry for the first time operating on a global scale, regional variations responsive to climates and cultures would flourish.

Blue is the New Green

A proposal to base a modular building system on intermodal transportation and global supply chain procurement raises a question: Does shipping building modules halfway around the world make environmental sense? The answer, which will come as a surprise, has two parts. First, maritime transportation is many times more fuel efficient than trucking, so the shipping distance across oceans translates into a fraction of the fuel consumed if that distance were traveled by a tractor-trailer over the highway. Overseas shipping is roughly ten times as efficient as truck transport (NRDC, 2012). Via the Panama Canal, the trip from Shanghai to New York is 12,000 miles, or the equivalent of 1,200 miles on the highway. Let's call this "Equivalent Trucking Miles", or ETM.

The second part of the answer has to do with weight. The quantity of fuel used to move materials, no matter what mode of transport, is proportional to weight. The all-steel VUC, having no concrete, at forty-one pounds/square-foot is approximately one-third the weight of a conventional steel-and-concrete building. Energy expended per square-foot of building area to transport a VUC is one-third of what it would take to transport the materials required to build one square-foot of a conventional building. That 1,200 ETM becomes, in effect, the equivalent of 400 ETM per square-foot (ETM/SF). Remember that under LEED, a Regional Priority credit is achieved by obtaining materials within 500 miles. A building comprised of VUC's would be 20 percent more efficient than a conventional building in which all of the materials met the requirement for Regional Priority.[1]

Scale, Scale, Scale

A globalized modular industry can meet the demand of a burgeoning urban population for mid- and high-rise housing, at a cost and level of quality that will encourage living in densely populated environments.

1: Under LEED, the metric is cost, not weight, but the larger point remains valid.

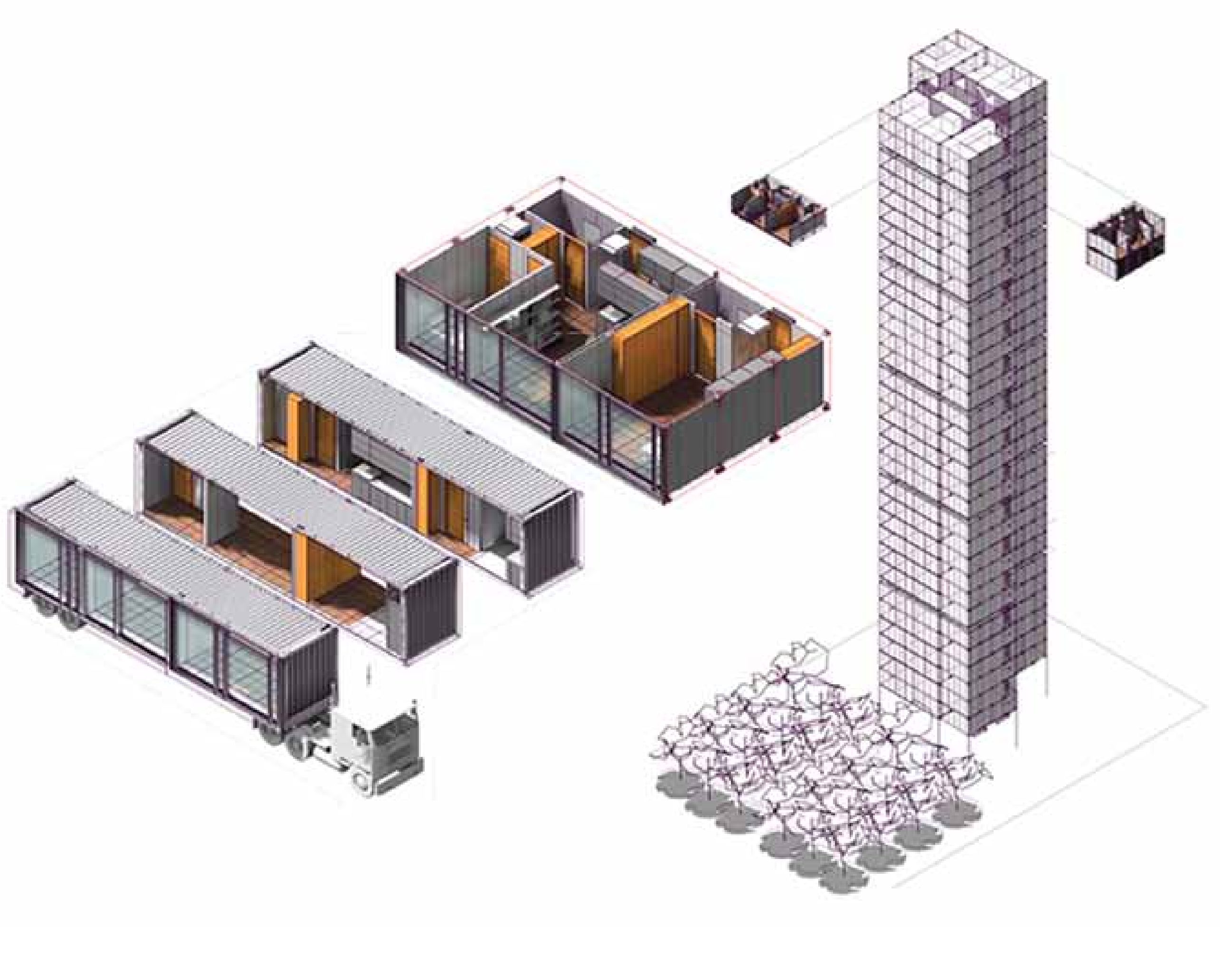
Opposite: The re-engineered building module is called a Volumetric Unit of Construction, or VUC. From a transportation standpoint it's indistinguishable from a standard shipping container. The VUC is fitted out on the inside with MEP systems, partitions, finishes, and fixtures. Façades are attached before craning. Source: FXFOWLE

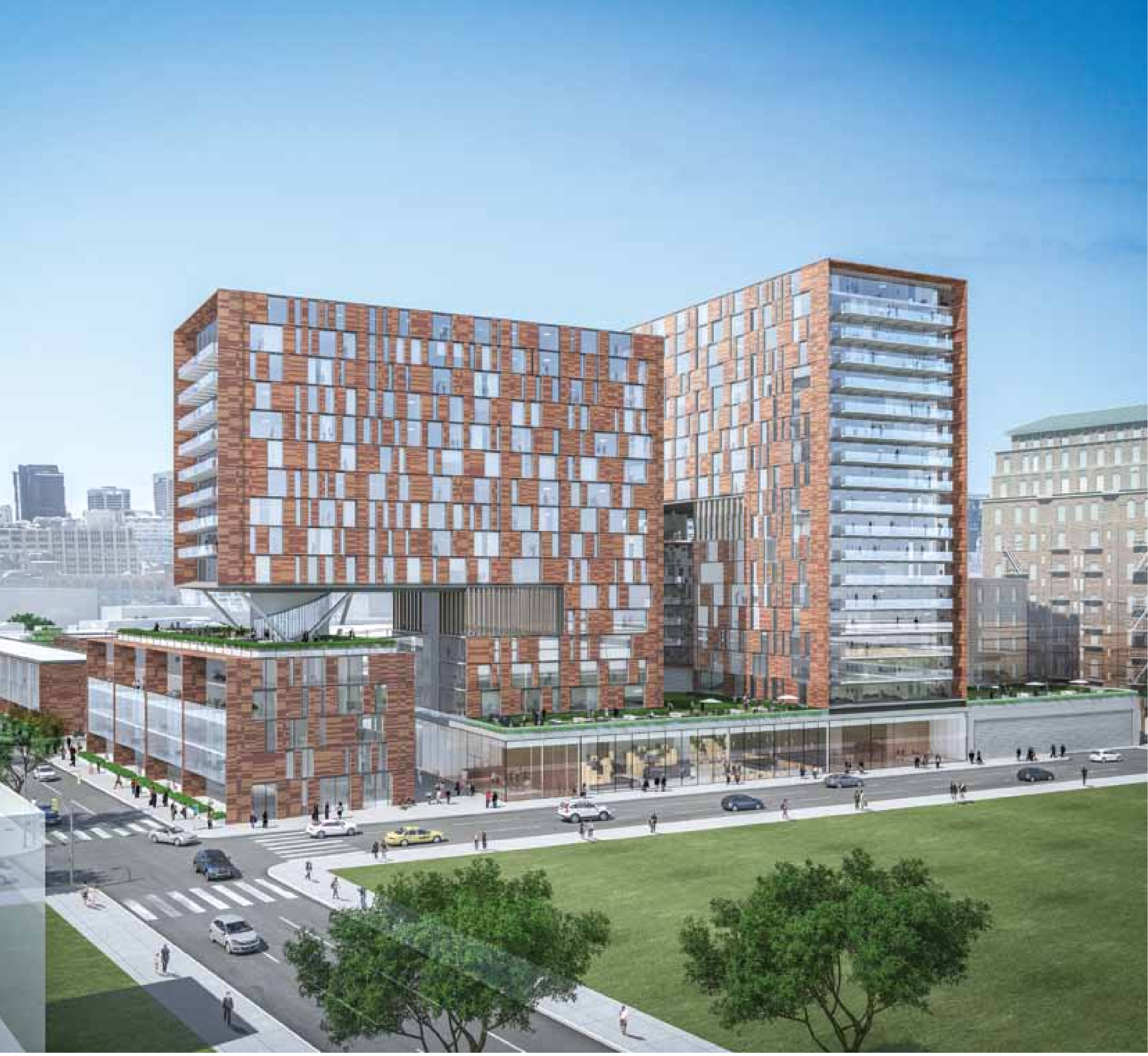
Bottom: VUCs can be arranged to create varied unit layouts and can be stacked into high-rise buildings. Elevators, fire stairs, corridors, interconnections and vertical services are integrated into VUCs as a "plug and play" system. Source: FXFOWLE

Scale matters above all else. Scale drives industrialization, advanced manufacturing technology, supply chain procurement, and modern quality control techniques. But scale in modular construction has proven elusive. To achieve scale in a contemporary enterprise global markets are required, and conventional modular manufacturing is locked in a regional cage of 200 mile trucking.

Breaking the chains of regional manufacturing means adopting intermodal transportation, the system by which standard shipping containers are moved inexpensively around the world by the millions each year. The introduction of containerized shipping fifty years ago revolutionized global trade, but until now a shipping container was a metal box stuffed with products - it was not the product itself.

A new type of building module – the Volumetric Unit of Construction – based on the shipping container but purpose-engineered to meet the specific and stringent requirements of mid- and high-rise building construction, retains the advantages of intermodal logistics and automated handling. Such a module would be the backbone of a completely integrated





building system that will spawn a new industrial ecology, an interdependent network of architects, industrial designers, process engineers, entrepreneurs, and building product manufacturers that will flourish within a global market, leveraging the power of distributed intelligence. Dimensional standards and rules that govern the arrangement of components - an architectural operating system - will provide behind-the-scenes support for a growing open-source catalog of apps. An expanding web of connections among stakeholders and start-up enterprises will ignite a global architectural conversation from which a new kind of architectural vernacular will emerge, in which regional differences - cultural, environmental, historical - will find expression within a system of broadly accepted technical standards.

The challenge, then, is how to achieve scale through diversity, differentiation, and local adaptation, and critically, to encourage urban density and discourage sprawl - taking us full circle back to the related problems of land use and construction costs. By significantly reducing the cost and increasing the quality of mid- to high-rise construction, a modular building system utilizing global transportation offers an environmental, social, and economic solution.

Top: A study for a 536,000 SF residential development over a conventional retail base, comprising 1,621 standard VUC's arranged into high-rise, mid-rise, and townhouse typologies. Source: FXFOWLE

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