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Space as Product

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Abstract

At a time when building construction efficiency has decreased by four percent since the 1960s, efficiency in automotive manufacturing has increased by 400 percent, largely due to implementation of robotic manufacturing. The world needs to build two billion new homes over the next 80 years (that is 25 million per year). Worldwide automotive production hit 73.5 million units in 2017. A new construction paradigm needs to be created to increase efficiency, improve quality, and reduce cost for the millions of houses that need to be produced in developing countries around the world. Learning from the manufacturing processes of the automotive industry, modular high-rise housing should be built using robotics and mass production, not unlike the automotive industry. This paper explores the use of potential "spare capacity" of automotive manufacturing facilities to create high-density, high-rise housing modules. There are viable solutions around modular, in terms of method/process, materiality, typology, and the human experience.

Keywords: Design Flexibilty, Global Impact, High-Rise, Modular Construction, New Construction Methods, Social Responsibility

Introduction

"You can have any color as long as it's black. "

— Henry Ford (Ford and Crowther 1923)

Productivity in the design and construction industry has decreased by four percent from the 1950s to today. Many significant global industries, including automotive, aviation and furniture fabrication, have increased productivity three-to-fivefold over the same period.

"If construction-sector productivity were to catch up with that of the total economy—and it can—this would boost the sector's value added by an estimated US$1.6 trillion, adding about two percent to the global economy, or the equivalent of meeting about half of the world's infrastructure need. One-third of the opportunity is in the United States" (MGI 2017).

Based on UN Habitat statistics, the world needs to build more than two billion new homes over the next 80 years. This equates to 25 million homes per year. China urbanized 300 million people over the last 20 years. That equates to creating approximately five million homes per year. In other words, even if the United States were to build at the incredible scale and breakneck pace seen in China, we would still be short 20 million homes per year (see Figures 1 and 2).

For reference, the automobile industry has increased productivity by over 600 percent over the last 60 years. This has largely been a result of restructuring the core construction of the automobile and the introduction of automated production. The integration of the frame and body into a "unibody" was one significant move that made cars lighter, stronger and faster to build. Furthermore, robotic technology in production and assembly allowed for far greater efficiency and reliability. In 2017, worldwide automotive production hit 73.5 million cars. Twenty-nine million of those cars were produced in China, and 11.2 million in the United States.

Figure 1. Despite construction booms in China, much of the country's older housing stock is aging. © Paul Henri Degrande

Figure 2. Hong Kong is one of the densest cities in the world. © skeeze

By now, the parallels between the construction and automobile industries become clear. It is time for the design and construction industry to move forward to innovate new concepts, processes, and technologies to design and construct buildings.

"Parts of the [construction] industry could move toward a manufacturing-inspired mass-production system, in which the bulk of a construction project is built from prefabricated, standardized components off-site in a factory. Adoption of this approach has been limited thus far, although it's increasing. Examples of firms that are moving in this direction suggest that a productivity boost of five to ten times is possible." (MGI 2017).

Housing that is humane and affordable is a serious issue around the world in both developing and developed countries. The focus of this paper is to consider the possibilities for a new way of creating modular high-rise residential buildings by considering space as a product. This paper will examine four major dimensions:

1. Rethink the stick-built nature of current modular construction to produce a "kit-of-parts design" that is integrated, uses less material, and is flexible
2. Fabricate buildings through automated production, via robotics similar to that used in automotive manufacturing

3. Explore ways to vary the module and its expression using mass customization
4. Integrate nature and living with designs that consider the human condition

This paper will present a "design case study" that conceptually portrays the major benefits described. This case study will consider the overall concept, planning, massing, and unit design to explore the opportunities for innovation and productivity. Key elements such as reducing material quantity, creating architectural variety, creating usable outdoor green space, and fostering higher degrees of integration between structure, infrastructure and finishes will be examined.

Rethinking the Modular Paradigm

Modular construction is not new, yet it is surprising that it is not more widely adopted by the design and construction industry today. From first-hand experience, there are a number of reasons that have limited the proliferation of this typology:

- Most designers are frustrated with the perceived amount of design limitations in this process.
- Many fabricators do not have the backlog or throughput to optimize the manufacturing set-up.
- Many companies pursuing modular approaches employ construction techniques similar to construction in the field—yet carried out indoors with human labor in a warehouse.
- No one is thinking deeply enough about designing housing for the underserved.

The modular building industry is generally thought to have started in 1895 when Sears Roebuck and Company started selling building material kits. An argument can be made that modular building's origins were perhaps even earlier, in the 17th century, when settlers in Massachusetts constructed homes with prefabricated materials from England. However, the Nakagin Capsule Tower, designed by Kisho Kurokowa and located in the outskirts of Tokyo's posh Ginza district, was one of the first to represent the future potential of modular buildings in a densely-urbanized world (see Figure 3). It was built in 1972 in just 30 days:

"A total of 140 capsules are stacked and rotated at varying angles around a central core, standing 14 stories high. The technology developed by Kurokawa allowed each unit to be installed to the concrete core with only four high-tension bolts, which keeps the units replaceable. Each capsule measures 4 x 2.5 meters, permitting enough room for one person to live comfortably. The interior space of each module can be manipulated by connecting the capsule to other capsules." (Sveiven 2011).

Today there are a number of companies exploring the modular building space. Many set up "stick-built" construction lines in warehouses and use human labor to assemble steel-frame "boxes" in a controlled environment. "While off-site

Figure 3. The Nakagin Capsule Tower was completed in Tokyo, Japan in just 30 days.
© Jordy Meow (cc by-sa)

construction—including prefabrication, modularization, preassembly or off-site multi-trade fabrication—has been around for decades, it is emerging as a critical method for delivering projects faster, in a safer and cheaper manner in today's labor-constrained engineering and construction (E&C) environment" (Hoover et al. 2018). This process has the potential to incrementally save time, money and increase quality. A current leader in full modular building construction includes the Netherlands-based hotel chain, citizenM, which is reinventing affordable luxury hotels for budget travelers.

In Japan, where more than 15 percent of the country's one million homes and apartments are factory-built, companies such as Sekisui House, a subsidiary of the Japanese Chemical Company, and Panasonic's home brand PanaHome, are taking on modular housing. "Millions of buildings now standing in Japan were prefabricated, and several Japanese companies regularly produce more than 10,000 new prefab homes every year" (Berg 2017). Meanwhile, in the United States, Champion Homes is one of the largest North American off-site homebuilders, and startups from California (Katerra) and New York (Full Stack Modular) are seeking to transform the industry with tech-driven off-site construction methods.

Yet the results have been mixed. Unfortunately, the press has singled out failures in the process rather than advancements. The key to overcoming these obstacles is to move towards a far more radical idea of the modular typology. As a fully-integrated idea, it aspires to save material and seamlessly integrate all of the building systems, producing a far greater impact on time, cost and quality, akin to that achieved by the automobile industry unibody scheme advanced in the 1960s and '70s. Cars using the unibody system use on average 20–30 percent less material than body-on-frame cars (see Figure 4). They optimize material composition and integrate lighter materials such as aluminum and carbon fiber. In addition, by incorporating advanced robotics in the production and assembly process, these cars are safer to build and safer to drive (see Figure 5). Today the automobile industry continues to advance, using stronger and lighter materials, such as polymers, to reduce weight.

To illustrate the proximity of this idea, consider the example of a Mercedes-Benz Sprinter Van (see Figure 6). The basic vehicle is around 1,400 cubic feet (39.6 cubic meters) in volume, weighs about 8,550 pounds (3,878 kilograms) and the floor area is around 20 by 7 feet = 140 square feet (6 by 2 meters = 12 square meters). The weight includes an engine, which in our high-rise modular housing model would be the mechanical unit for the module. Further refinements could include full-surround audio, refrigeration and a furnished interior. It wouldn't take much to scale this 150 percent and have a "studio" apartment complete with a self-contained power plant.

Figure 4. The integration of the frame and body into a "unibody" was one significant move that made cars lighter, stronger and faster to build. © Aero7 (cc by-sa)

Figure 5. Robotic technology in car production and assembly allows for far greater efficiency and reliability. © Siyuwj (cc by-sa)

Housing Module as "Unibody"

A key to gaining more efficiency in construction is to look to similar technologies in other industries. Using robotic technology to increase the efficiency and quality of the construction process can and will be a game-changer. An initial focus on modular "unibody" shells could be done robotically by assembling mass-produced components stamped out of steel. This will reduce material quantity, create lighter modules, and be much stronger. Further development and integration of building systems such as electrical harnesses and plumbing fixtures could be fabricated and seamlessly integrated during robotic assembly. Additional products could be installed, including final finishes as well as bathroom and kitchen components. The cost of entry into robotic fabrication and manufacturing is very high, so a sustained volume of production will be key. This would suggest mass housing needs could suit this method well.

Figure 6. The Mercedes-Benz Sprinter Van provides a useful example of lightweight, modular, unibody construction. © Daimler AG

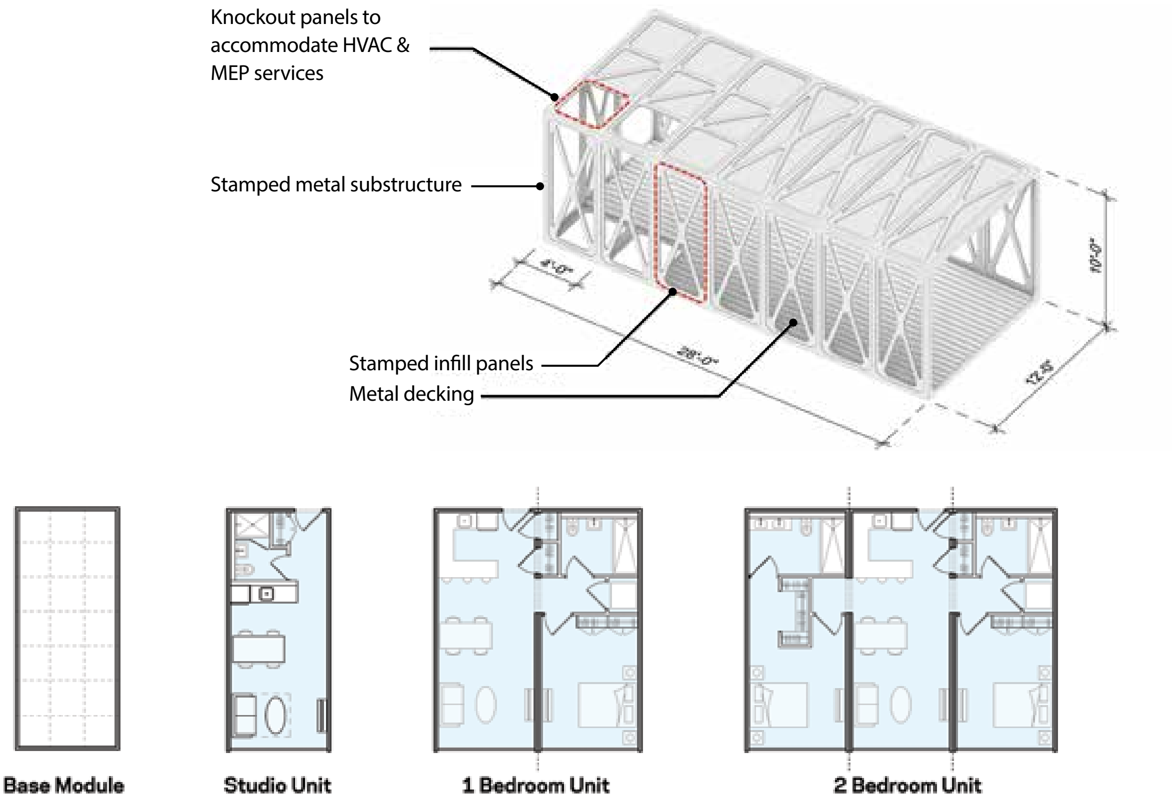


Figure 7. "Unibody" housing module. © NBBJ

One obvious shortcoming to modular buildings has been the relentless repetition and lack of variety. This is one of the reasons most designers are less interested in this type of process. However, there are endless possibilities for overcoming this constraint. Working off the basic "unibody" chassis, there are multiple expressions that can articulate the facades of a building. These "attachments" could respond to climate, culture, and artistic choice. Another area of exploration includes the interior layouts. Today's lifestyle supports a more open and flexible living environment. Core infrastructure such as mechanical, electric, and plumbing systems, need to be strategically placed to allow for products to support living and respond to a region's specific market and geographic needs.

One last area of tremendous importance to any typology today is access to nature. Integrating nature seamlessly into the built environment is critical. Studies show the significant positive effects of health, wellness and productivity related to proximity to nature.

"One of the great challenges of our time is to bring the beneficial experience of nature into the design of contemporary buildings, landscapes, communities, and cities." (Kellert 2018).

Therefore, to humanize modular buildings, thoughtful integration of nature is a must. The below case study will examine rational and effective ways to integrate open green space for both communal and private use. This consideration will also directly correlate to a more unique end result. Modular outdoor areas and planted terraces will be defined within the kit-of-parts and provide new and unique varieties to be explored for each site-specific location.

The key to modular projects, and in particular residential, is a process that produces more cost-effective, faster and higher-quality buildings in a more humane way. The following case study will discuss these initial possibilities.

Case Study

To begin, let's start with the "unibody" module. The module is 12 x 28 x 10 inches (3.6 x 8.5 x 3 meters) tall. Although a standard shipping container is 8 feet (2.4 meters) wide, 8.5 feet (2.6 meters) tall, and 20 feet (6 meters) or 40 feet (12 meters) long, the more comfortable standard for the living module is a bit larger. This will require special permits for transportation; however, most jurisdictions will accommodate such loads (see Figure 7).

Within the module, there is flexibility to plan various living conditions and room types. The idea of having a core module that includes the major HVAC, electrical and plumbing riser and equipment would allow bathrooms and kitchens to plug into this module. Furthermore, other rooms can plug-and-play off this core module, and each space could feature customizable layouts and appliances. The core module or studio can then be added to create one-bedroom and two-bedroom configurations, as well as duplexes. This level of variety still fits within the overall module, but also creates diverse living conditions (see Figure 8).

Finally, the integration of nature occurs in three ways: 1) green planted terraces, 2) open green "voids" and 3) rooftop green spaces. Depending on the region, these green spaces could include beds for locally-sourced, low-maintenance plants, like ornamental grasses, dwarf shrubs and flowering perennials. These areas could also feature small communal vegetable gardens and dog "parks", and serve as places for contemplation, social gatherings or summer activities. Stacked modules create a market-driven unit mix, while multiple green amenities are key to the final building design as culturally-relevant and unique (see Figures 9 and 10).

Integral to the efficiency of this system is the preinstallation of the exterior enclosure. Each module will have its front exterior face fabricated and installed in the factory. Gasketing and final fascia will be installed in the field to make the stacked modules weathertight. This is also where articulated elements and attachments—such as sun screens, fins, louvers and even shallow balconies and planter boxes—can be added to the exterior face to provide variety as well as adaptation to geography and culture (see Figure 11). This will allow each project to have a unique character, customizing it for its location and adding meaningful and relevant artistic expressions.

Each core module will be set within an infrastructure frame that includes site-built cores, such as elevator and stair towers. These elements will create the overall structural framework for the modules. A base podium will create a structural platform at the second or third level, which will then allow the modules to be vertically stacked. It is anticipated that this type of modular construction can efficiently rise 20 to 30 stories (see Figure 12).

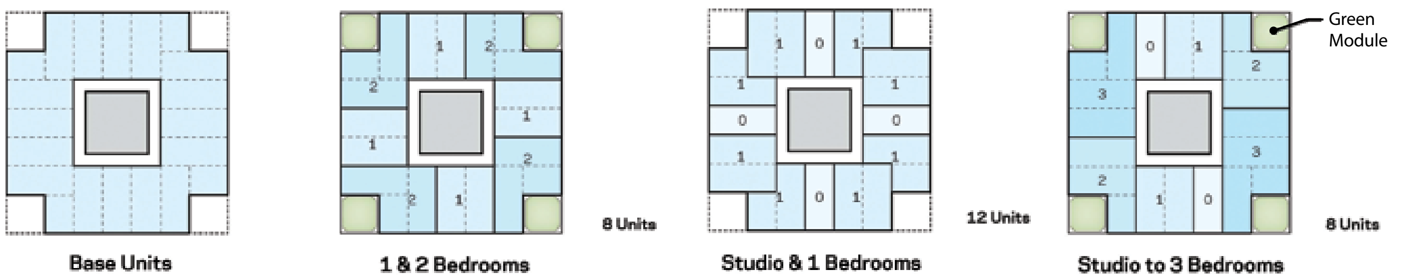


Figure 8. Flexible unit yield. © NBBJ

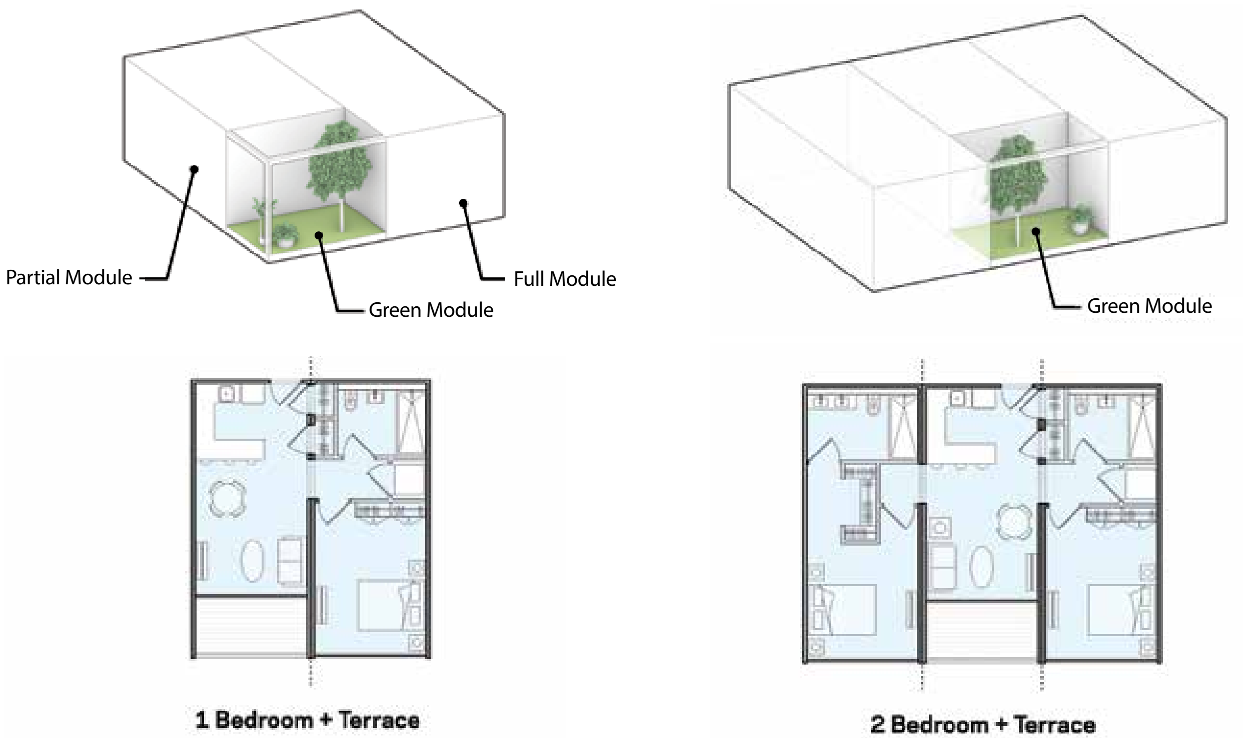
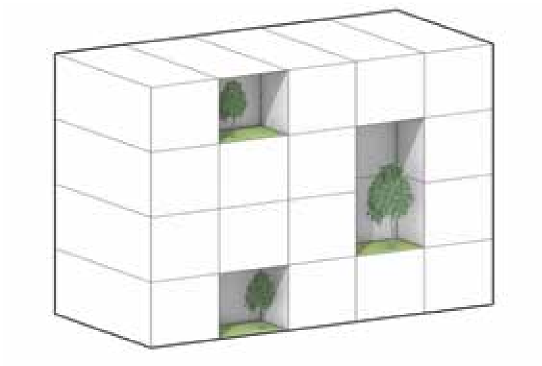


Figure 9. Outdoor space strategy. © NBBJ



Program variety through pocket green spaces

Additional variation through exterior articulation

Figure 10. Program variety and exterior articulation options. © NBBJ

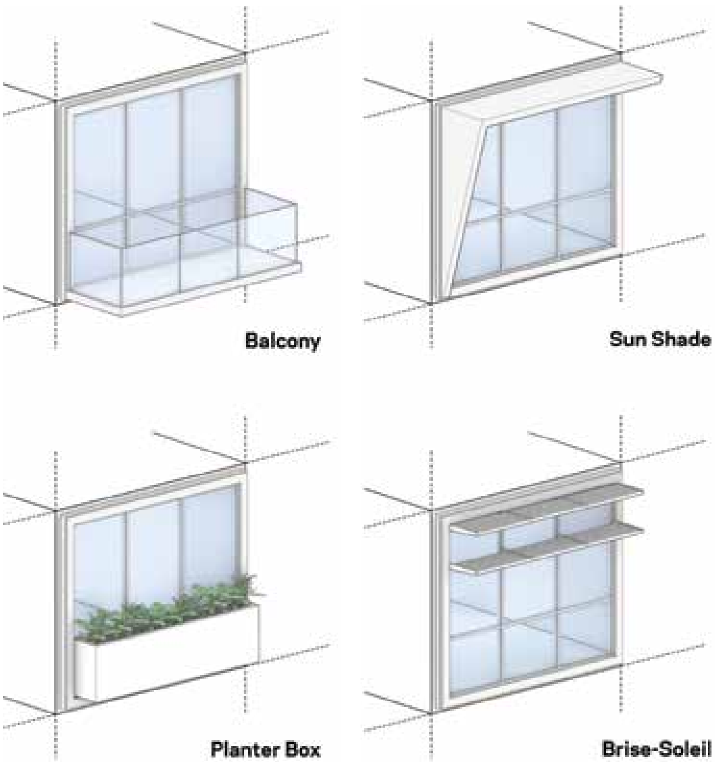


Figure 11. Façade components. © NBBJ

Takeaways and Closing Thoughts

This study illustrates that there is a pathway to a brighter future with modular buildings and construction processes. By no means is this an exhaustive, engineered concept that solves all the issues surrounding the potential challenges for this industry. The industry is seeking to address areas such as: field labor retraining to program and supervise robotics, transportation logistics, new financing structures and systems integration, among many others, to make this idea viable.

Additionally, this study is meant to look at the massive opportunity to change the nature of this industry. To look into another industry—the automobile industry—and find parallels that we can exploit for the construction of space is a key takeaway. It is feasible to render space as a product that can be mass-produced, efficiently, cost-effectively and at a higher level quality, to serve the enormous needs of the global mass housing market today. To consider meeting the needs of society for today and tomorrow, a major rethinking of design and construction needs to take place, given the rising cost of materials:

"Construction prices nationwide have risen about five percent per year for the past three years, according to the Turner Building Cost Index. Costs have gone up even faster in big cities and across California, according to RSMeans, a unit of Gordian, which compiles construction data. In the Bay Area, builders say construction prices are up 30 percent over the past three years—so much that even luxury projects are being stalled by rising costs." (Dougherty 2018).

It is paramount that the industry continues to innovate and seek new ways of moving forward:

"It is hard to argue that housing is not a fundamental human need. Decent, affordable housing should be a basic right for everybody in this country. The reason is simple: without stable shelter, everything else falls apart." (Desmond 2016).

The future of our communities, towns, cities and planet depends on a more assertive development of design technologies.

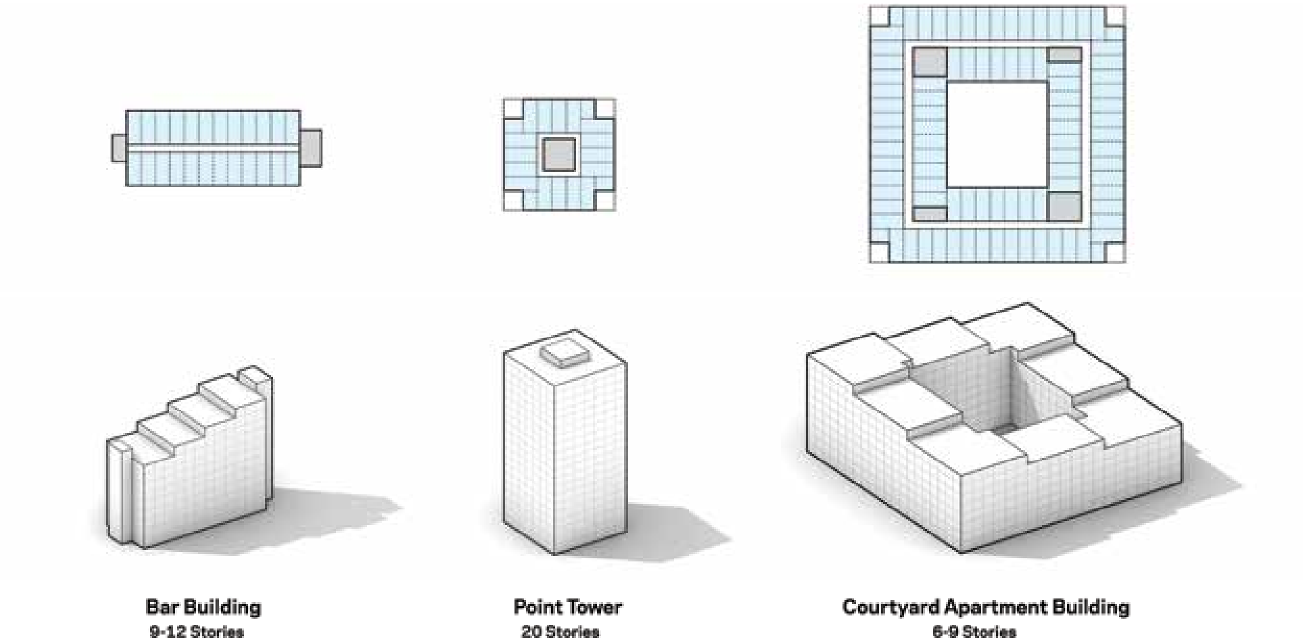


Figure 12. Residential building typologies and components. © NBBJ

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