Fabulous Pre-fab

Applying Modular Construction to Multifamily Residential Projects in Washington, DC

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Hello!

1 Welcome to iLab

iLab exists to promote innovation and progressive architecture and design through internal research sponsored by Hickok Cole Architects. The program creates a gap in day to day work life to foster innovation. The firm crowd sources the most compelling proposals, every employee votes, and the winners are awarded uninterrupted project-free time to develop an idea or project. Through this exploration the firm aims to stretch conventional notions about architecture, fabrication, work styles, and entrepreneurship.

2 What You’ll See Here

This document is the result of Abigail Brown’s iLab project “Fabulous Pre-fab: Applying Modular Construction to Multifamily Residential Projects in Washington, DC.” Modular construction is a pre-fabrication system in which modules of a building are constructed in a factory then shipped to the site and assembled on a foundation. This system has not yet been widely used in Washington, DC, despite the cost, schedule, and environmental benefits it offers and the successful use of the system in other major cities. This document records answers to the three major research questions that drove the investigation: what’s modular?, why and why not use modular?, and what can modular be? This research was tested with a speculative design for a real site in Washington, DC, with the intention of introducing this technology in future Hickok Cole projects.
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Disruptive Innovation

What’s Modular?
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What’s Modular?

Introduction

Modular construction consists of whole building units prefabricated under controlled conditions and transported to the construction site on a flatbed trailer. These units are lifted into their final location on a foundation that is constructed ahead of delivery. In the past, only buildings which employed a repetitive plan were built using modular construction since exact repetition was the only way to achieve economies of scale. This resulted in buildings that were often banal and homogenous. However, this boundary has been pushed by advances in technology that allow mass customization to replace exact repetition. Modules can come together in a number of ways to create an incredible variety of spatial forms including large span spaces. Although almost any building can be divided into modules, certain project types will receive the greatest economic benefit. This includes taller urban buildings, especially multifamily residential projects.
Why Modular?

1. Faster Schedule

The shortened construction schedule due to the ability to perform site work and building construction simultaneously is the greatest cost savings opportunity on a modular construction project. DeLuxe Building Systems estimates that construction times can be cut up to 50%. Reducing the time that large expenses such as cranes and hoists are needed on a site is a further reduction of overall cost. Modules can typically be installed at a rate of 6-10 modules per day depending on site conditions.

2. Cheaper Labor

Work done in a factory can be done quicker than work on-site due to the controlled climate, factory organization, and optimized repetition of tasks. In addition, the same amount of work can be done with a smaller crew size. Base wages for tradesmen in a factory setting are typically lower than on a traditional site as well; however, even in the event that factory workers are paid the same as on-site workers the smaller crew size and reduced schedule would still result in opportunities for cost savings. Modular construction is especially cost competitive against conventional construction built with union labor.
Why Modular?

3 Higher Quality

On-site construction is characterized by the process of concealing previous work with successive layers of materials. Conversely, modules expose more surfaces and spaces throughout the construction process, which allows better access to a greater number of building components after finishes have been applied. The work is surrounded by open factory space and not subject to many interior space constraints.

On a typical construction site, day-to-day quality is typically a function of the superintendent or general contractor who is concerned with many other aspects of the construction process. Modular construction allows for the ability to more closely monitor work quality. Quality control is a very methodical and consistent process performed at each assembly station, which eliminates error and reduces the time needed to perform quality checks at the end of the line.

4 Less Exposure to Weather

Many of the indoor air quality issues identified in new construction result from high moisture levels in the framing materials. The potential for high levels of moisture trapped in building materials is reduced with modular construction since the modules are assembled in a dry factory setting. The factory setting is monitored and controlled for proper air quality and ventilation.

5 Worker Safety

Conventional construction workers regularly work in less than ideal conditions dealing with temperature extremes, precipitation, wind, and sun exposure. Safety risks, such as potential for injuries including falls, is much higher in the field.
Why Modular?

6 Less Materials Waste

Modular construction makes it possible to optimize construction material purchases and usage while minimizing on-site waste. While there is some redundancy since the joining of modules creates a double wall condition, cost control can come from the fact that manufacturers buy material in bulk and often in advance or immediately upon contract execution which helps to avoid material cost escalation. Bulk materials are stored in a protected environment safe from theft and exposure to the environmental conditions of a job site. One of the most applicable LEED credits to modular buildings is LEED 3.0 BD+C, MR Credit 2.1 and 2.2, Construction Waste Management, which aims to reduce waste generated on site.

7 Less Environmental Disturbance

Because building modules are fabricated off-site it is possible to achieve tighter site control. The duration and impact on the surrounding site environment will be reduced, which makes it a good choice for greenfield sites or urban infill. This construction technique can assist in the earning of LEED 3.0 BD+C, SS Credit 6.1, Site Development - Protect and Restore Habitat, which rewards construction techniques that limit site disturbance and keep disturbed areas to within the area immediately adjacent to the building footprint. The limited site disturbance also comes in handy when a site has limited room for a staging area.

Modular construction takes a lot of less mess and noise produced by construction out of the city and behind the walls of a factory. This is an advantage for projects that are highly controversial or with difficult neighbors.
Why Not Modular?

1. Deeper Structure

Since each module has independent walls, floor, and ceiling, and since these modules are stacked side-by-side and on top of one another, there are some inherent redundancies in the construction of a modular building. These double walls and floors provide some architectural benefits. For example, the double construction increases the acoustical ratings of the assemblies. However, it also results in a deeper floor structure and wider walls at module mate-lines than would typically be found in a multifamily residential project. The result is either a taller, wider building, or shorter ceiling heights.

**Standard enclosure dimensions:** steel modular construction versus cast-in-place concrete
Why Not Modular?

2 Cheap DC Labor Rates

Modular construction is financially competitive when compared to conventional construction built with union labor. For this reason, cities like New York and Philadelphia have seen an upswing in modular construction projects in recent years. Unfortunately, labor rates in Washington, DC, are typically lower than those in other major cities where there is a stronger union presence. This means modular may not make financial sense in DC unless the labor landscape changes.

3 Market Perception

A major challenge of introducing modular construction to a new market is the negative perception of modular housing, which is often associated with trailer parks, public housing, and low-end hotels. Combatting this negative perception requires showing clients how to take advantage of the unique architectural opportunities and increased construction quality that modular allows. It is important that modular housing does not “look like” pre-fab housing, but rather like than other multifamily housing project. Marketing messages and positive media coverage are important, as they influence the opinions of potential residents.
What Can Modular Be?

Market-Rate Apartments

Mid-Rise Fabulous Condos Steel

Innovative Luxury

Hotel

High-Rise Sustainable

Student Housing Single-Family

Low-Rise Wood

Affordable

Local High Quality

High Quality Local

Wood

Innovative Iconic

Condos Luxury Steel

Low-Rise
What Can Modular Be?

BM Modular One

Bethesda, MD; Robert Gurney, FAIA

• 5,000sf single-family home
• Cost $200/sf; typical Robert Gurney houses cost $300/sf
• Took 2 weeks to build 13 wood frame modules in factory; 2 days to install on-site
• Took 6 months to complete after delivery of modules
• All finishes, appliances, and millwork were installed on-site
• Made no compromises in terms of quality of materials or construction
• Allowed a client who had budget and schedule limitations to afford a custom house
• Manufacturer: Nationwide Homes, Sandy Spring Builders
What Can Modular Be?

2 NYC Beach Facility Modules

New York, NY; Garrison Architects

- 37 lifeguard and comfort stations
- Built after Hurricane Sandy destroyed existing structures
- Needed to be built quickly (within five months, by Memorial Day 2013) and had to be capable of withstanding future extreme storms
- Deployed to fifteen sites around New York City
- Common chassis allowed modules to be modified for use as comfort stations, lifeguard stations, and offices while meeting a variety of site conditions
- Steel structure modules are 15 feet wide x 12 feet x 47 or 57 feet long
- Modules include solar hot water heating, skylight ventilators, and PV panels
- Manufacturer: DeLuxe Building Systems

Bathroom pods built using modular construction; NYC Beach Restoration Modules, New York, NY; Garrison Architects
NYC Emergency Housing Prototype

New York, NY; Garrison Architects

- Disaster housing prototype designed for the New York City Office of Emergency Management
- Multi-story, multifamily interim housing designed to work across the country
- Modules could be deployed in less than 15 hours and assembled in various arrangements calibrated for challenging urban conditions
- A 3-story, 3 unit test structure is installed in Brooklyn, NY, and is currently undergoing occupancy tests
- Steel modules are 12 feet wide x 40 feet long
- Manufacturer: Mark Line Industries
What Can Modular Be?

4. The Modules at TempleTown

Philadelphia, PA; Interface Studio Architects

- 80,000sf, 5-story building was built from excavation to completion in 9 months
- Includes ground floor parking garage and 60,000sf of modular construction above
- Total of 89 wood modular units to build 72 one and two-bedroom apartments
- Cost was approximately $135 per square foot
- Modular construction helped keep costs down without compromising quality
- One of the largest LEED for Homes development in the US
- Used modular construction as part of the branding for the building
- Manufacturer: Innovative Design & Building Services with Excel Homes

Mid-rise student housing built using modular construction; The Modules at TempleTown, Philadelphia, PA: Interface Studio Architects
What Can Modular Be?

5 One9 Condominiums

Melbourne, Australia; Amnon Weber Architects

- 9-story, 34 unit condo building erected in 5 days in November 2013
- One and two-bedroom market rate units include high-grade contemporary finishes
- Building comprised of 36 modules built off-site complete with facades, finishes, and balconies; cantilevered terraces on all levels
- Facade includes double glazed windows and sliding privacy screens
- Built with the Unitised Building (UB) System, a modular pre-fab system developed and used in Australia
- Manufacturer: Hickory Group, Vaughan Construction

Mid-rise market rate condos built using modular construction; One9 Apartments, Melbourne, Australia: Amnon Weber Architects
What Can Modular Be?

Atlantic Yards B2

Brooklyn, NY; SHoP Architects

- 32-story, 350 unit tower will be the tallest modular building in the world
- As of June 25th construction was up to the seventh floor
- Had some delays at the beginning, but the process is speeding up
- 60% of work done in factory, 40% on site
- Estimated to trim construction schedule from 24 to 18 months
- Housing will be 50% at market rate, 50% below market rate
- Includes 4,000sf of ground floor retail and luxury amenities
- Manufacturer: FCS Modular, Skanska and Forest City Ratner

High-rise modular apartment building currently under construction; Atlantic Yards B2 Tower, Brooklyn, NY: SHoP Architects
What Can Modular Be?

- Pushed
- Dramatic
- Stacked
- Terraced
- Courtyards
- Rotated
- Iconic
- Pulled
- Twisting
- Aggregated
- Dynamic
- Wrapped
- Innovative
- Textured
- Moveable
- Traditional
- Site-Specific
- Expressive
- Irregular
- Stacked
What Can Modular Be?

“Play with your architecture”

In keeping with Hickok Cole’s mantra that “good ideas can come from anywhere,” the entire Hickok Cole office was invited to a happy hour to help generate ideas responding to the question “What Can Modular Be?” Multiple massing studies were produced using blocks from the popular game Jenga. Cladding for modular buildings is usually installed entirely on-site using conventional techniques, through it can also be completely or partially attached in the factory. Installing the cladding on-site allows the building skin to act as a wrapper that encloses and covers the expression of the modules. If the cladding is installed in the factory it becomes much easier to identify the individual modules within in the overall composition of the building. Whether or not to express the modules is a decision that needs to be made for each project. The Jenga exploration revealed multiple ways that expressing the modules allows for unique architectural expression and controlled variety across a facade.
What Can Modular Be?

Stacked

Pushed & Pulled

Precedents and Jenga massing studies; stacked, pushed and pulled
What Can Modular Be?

Precedents and Jenga massing studies; rotated, terraced, courtyards
What Can Modular Be?

Precedents and Jenga massing studies; textured, aggregated, subtle
What Can Modular Be?

Twisting
Dynamic
Iconic

Precedents and Jenga massing studies; twisting, dynamic, iconic
What Can Modular Be?

Irregular

Dramatic

Composed

Precedents and Jenga massing studies; irregular, dramatic, composed
Design & Construction

How Does Modular Work?
Wood Structure

1 Principles of Wood Modular

Wood modular is used for single family homes and low-rise multifamily buildings. Wood modular buildings are limited in height and require a deep ceiling to floor connection. Wood modules are often finished with primed gypsum wall board before shipping, but appliances, millwork, and heavy finishes like tile and stone are installed after placement at the site. During transit, modules often require temporary bracing since the wood framing may not be engineered to withstand transportation loads.

2 Module Dimensions

Dimensional requirements for modular construction are determined by transportation restrictions and will vary by manufacturer. Wood is a lightweight structure, and therefore can accommodate large module sizes. These are rules of thumb:

- Maximum module width: 16’-0”
- Maximum module length: 64’-0”
- Maximum module height: 12’-0”
- Maximum building height: 3 to 4 stories
- Estimated depth of floor mate-line: 2’-0”

3 Construction Type

Building height and gross floor area are also limited by building code. Wood construction is limited to Type III or Type V construction.
Steel Structure

1 Principles of Steel Modular

Steel modular is used in buildings that require a more robust structural system such as taller, high-performing, or seismic-designed buildings. Steel modules have therefore become popular with West Coast architects and for mid-rise to high-rise multifamily buildings. Steel frames are strong and rigid and can be less stout since steel is stronger than wood and does not have to be unnecessarily over-structured for transport. The modules are finished out in the factory with insulation, infill framing, wiring, ducting, finishes, appliances, and millwork so they are as complete as possible before shipping. Modular construction manufacturers often specialize in either wood or steel modules.

2 Module Dimensions

Dimensional requirements for modular construction are determined by transportation restrictions and will vary by manufacturer. These are rules of thumb:

• Maximum module width and length using concrete deck:
  • 12'-0" x 46'-0"
  • 14'-0" x 40'-0"
  • 16'-0" x 35'-0"
• Maximum module width and length using cement board:
  • 12'-0" x 65'-0"
  • 14'-0" x 58'-0"
  • 16'-0" x 50'-0"
• Maximum module height: 12'-0"
• Maximum building height: 5 to 12 stories
• Estimated depth of floor mate-line: 1'-6"
Steel Structure

Construction Type

Steel modular construction is typically Type I or Type II construction, which allows for taller and larger buildings than wood modular. DeLuxe Building Systems uses steel floor joists with a 4.5” concrete deck as its typical module assembly. All structural members are wrapped with mineral wool insulation for fire protection and noise isolation. Once on-site the modules are bolted together in such a way that expansion joints between modules are not required.

Advantages of Steel Modular

• Higher fire resistance (Construction Type I & II) allows for taller and larger structures. Steel modular could be used for a 13-story DC high rise, and may prove to be cheaper than a cast-in-place concrete structure.
• Rigid and robust structure allows larger opening spans, reduced need for lateral bracing, and more design flexibility. Does not require temporary supports for transit.
• Matte lines are more structurally sound due to ease of connections and higher capacity of connections. Performs well under seismic stress and high winds.
• Structure is shallower than that required for wood modular.
• High level of prefabrication due to the strength and precision of the frame. Interior finishes, appliances, and fixtures are installed in the factory, which leads to greater time savings.
• Higher quality construction than both wood stick-built and wood modular. High quality will help mitigate the negative market perception of pre-fab as cheap construction.
Steel Details

1 Wall Thickness

Wall thicknesses vary depending on required fire rating and location of the wall within the module. The following are rules of thumb assuming the use of light gauge steel studs and 5/8” gypsum board:

- Interior wall on a mate-line: 8”
- Exterior wall (w/o cladding, w/ membrane): 9 3/4”
- When adjacent modules meet there is a 1/2” gap at the mate-line
- Interior walls not on a mate-line should use typical partition types

Multi-unit modular construction is inherently insulating to sound. Because each module has its own framing, there can be no direct sound transfer through the light gauge steel framing into adjacent surfaces.

2 Floor Thickness

Floor thicknesses vary based on manufacturer and structural system. Wood modules typically need 2'-0” of floor depth, and steel modules typically need 1'-6” of floor depth.

3 Openings Between Modules

The framing of a typical module results in a typical opening dimension of 8'-0”; however, openings as wide as 9'-6” are possible without significant structural modifications. If a clear span opening is desired, this can be achieved by increasing the beam depth or welding frames across the mate line.
Steel Details

Typical plan detail at exterior wall

Exterior wall section detail

Typical mate-line wall section
Project Delivery

1 Delivery Methods

There are a few standard routes that a client may take when going through the process of construction procurement for modular construction. These include design-bid-build, negotiated bid, and design-build.

Design-bid-build is the conventional method in which a project is designed by an architect and bid by competing general contractors. The selected general contractor then selects a subcontractor to provide the modular components. This delivery method does not take complete advantage of the potential collaboration benefits of modular construction; since modular manufacturers have their own systems, the production of bid documents becomes tricky. Bid documents can either use one manufacturer’s standard system as a basis of design (which limits competitive bidding), or bid documents can use a performance-based or prototypical system (which results in less architectural control of the final product and requires additional design work once a manufacturer is selected).

In a negotiated bid the architect and client select either a modular manufacturer or a general contractor who is teamed with a modular manufacturer at the beginning of the design process. This delivery method allows for maximum collaboration and more accurate pricing, as the selected manufacturer’s standards are used as known constraints during the design process.

In design-build procurement the client and modular manufacturer enter into a single contract in which the modular manufacturer can either do the design in-house or hire an outside architect as a subcontractor.

2 Construction Documents

There are three different ways in which collaboration between the architect and manufacturer may occur to prepare construction documents:

- The architect produces a set of construction documents and the manufacturer then produces shop drawings based off this set.
- The manufacturer may be involved from the beginning in an advising role and then will begin to produce drawings at a stage in between final design development and 50% construction documents. DeLuxe Building Systems uses this model.
- If using design-build, the architect may produce “bridging documents” that are given to a manufacturer to complete in-house.
Approvals

1 Permits & Inspections

Because modular buildings are constructed at a distance from municipal building inspectors, a third-party inspector system has been established. Inspectors must visit the modular manufacturing facility for inspections of the modules, then visit the site again after assembly. Permits are also often run through a third-party system. In the permit drawing set, modular and in-situ components should be represented together as a final whole. However, drawings should still clearly differentiate site work from modular components.

In Washington, DC, Brookland Equity Group LLC was issued a permit for a three story, four unit shipping container apartment building in July 2014. The containers were assembled less than two weeks after the permit was issued. Though shipping containers are a different kind of pre-fab than modular construction, this proves that modular buildings are able to receive building permits in Washington, DC.
Regional Manufacturer

DeLuxe Building Systems; Berwick, PA

- Founded in 1965; began using steel frame modules in the mid-1980s
- Two quarter mile long production lines, materials are procured locally when possible
- Nearly 400,000sf of production and warehouse facilities
- Metal fabrication and concrete plant on site; roll own studs and structural steel
- Capacity to produce 12.5 million sf per year
- Primary market sectors are hospitality, student housing, apartments, and condos
- Previously worked with Hickok Cole on the unbuilt 16th & Constitution project

Factory assembly line; DeLuxe Building Systems, Berwick, PA
Factory Fabrication

Factory assembly line; DeLuxe Building Systems, Berwick, PA
Factory Fabrication

Factory assembly line; DeLuxe Building Systems, Berwick, PA
Transportation

1 Transit Protection

All modules that are exposed during transport are covered by a custom made polyethylene sheet or tarp for temporary weatherproofing. In addition, any loose appliances or materials must be tied down prior to shipment.

2 Shipping

Maximum width, height, and weight of modules are based on shipping restrictions and are limited by individual state laws. City and county governments also impose additional regulations, which might include permit requirements, police escort, maximum dimensions, times of day, roads, route reporting requirements, and maximum weights. Modules can be shipped via truck, railroad, or ship depending on destination. For economic feasibility, the maximum distance from factory to site is typically considered 500 miles.

3 Vehicle Permits in DC

Permits are required for vehicles and loads wider than 8 feet-6 inches, higher than 13 feet-6 inches, longer than 55 feet, or that exceed the District axle and gross weight limitations (21,000 lb for single axle, 34,000 lb for double axle). In addition, police escort is required for any vehicles and loads that are wider than 12 feet, taller than 13 feet-6 inches, longer than 75 feet, or that weigh over 120,000 lbs. Police escort is also required for any vehicle carrying Class 1 Explosives. Refer to DDOT’s Public Space Permit Office for further information on Oversize and Overweight Vehicles.
Foundations

1 Foundation Types

In all cases the foundation must be prepared before the modules begin to arrive on site. Almost any foundation system can be used with modular construction depending on the site and soil conditions. Wood modules generally place distributed loads on foundations whereas steel framed modules often produce a point load. Therefore, perimeter and pier foundations systems are more common for steel buildings. Concrete podium construction is a good choice for multi-family buildings since it allows for the larger spans required for parking and retail at the site with the residential modules placed above.

2 Tolerances and Levelling

The levelling of foundations or grade beams is crucial to the subsequent installation and alignment of modular units. Often it is necessary to provide for some adjustment in the foundation or in the legs of the modular unit. Each manufacturer had developed its own proprietary system for locating and fixing mechanisms to aid in the positioning of units on the foundations. Generally base plates, steel strips, or cement particle board are fixed to the foundations and grouted and levelled as necessary to take up any inaccuracies in the top of the foundation.
Installation

Crane and Rigging

The type of crane required for placing modules is based on weight and reach. Positioning of modules often requires a crane of greater capacity than those commonly kept on-site during typical low-rise construction projects, as a 40-75 ton capacity is generally required. Various types of rigs are available to lift modules.
Installation

2 Hoisting and Positioning

Typically the modules are lifted directly from the flatbed trailer into their final location. An on-site crew guides the modules into place and make the connections. Ideally, this process does not impede the maximum workflow of the crane, as renting large cranes are expensive. The maneuvering of modules is performed by guide ropes. Weather conditions will prevent the placing of modules when wind speeds exceed 10 mph. A small gap between module frames allows the process to occur with greater speed. Any joints or openings are covered with a tarp at the end of each day. Most manufacturers can install 6-10 modules per day, depending on site conditions.

3 Fastening

Each modular construction manufacturer uses a different system to connect the modules to each other; however, it is typical to use an interlocking system to increase accuracy and reduce setting time. In most cases a pin is welded to the base of each corner column which fits into the columns of the module below. In the Kullman Building Corporation’s system, the tapered pin locates the module below, the diamond pin registers alignment in one direction, and the two floating pins allow for error. A 3/8” steel plate with a 1-1/2” stiffening lip at the top and bottom then fastens the modules together with blind rivets.
Roofing

1 Flat Roofs

All currently used roofing systems can be applied to modular buildings. The ceiling structure of the upper modular units can support the roof directly or an additional roof structure that spans between the walls of the modular units may be used. In either case it is necessary to ensure that the structure is designed to accommodate all roof loads. A range of flat roofing systems can be used, including single layer or built up membranes on sheathing laid on furring strips. The roof structure can be engineered to accommodate a green roof or assembly space. It is unlikely that pools can be accommodated on the roofs on modular buildings.

Parapet wall details are possible. Roof drain pipes can be incorporated into the vertical service shafts that also accommodate soil and vent pipes and other vertical services within the building. A parapet roof can be integrated into the construction of a module in the factory or constructed conventionally on site.

2 Pitched Roofs

Pitched roofs can be constructed in the factory as independent modules that are installed on site, constructed conventionally, or integrated into the construction of a module at the factory if it is low-sloping. Detailed research on pitched roofs was beyond the scope of this document since they are rarely used for multi-family residential buildings.
Exterior Cladding

1 Wall Cladding Interface

Cladding for modular buildings can be self supporting vertically and only supported laterally by the units, or it can be supported entirely by the modular structure. Cladding is usually placed entirely on-site using conventional techniques, through it can sometimes be completely or partially attached in the factory. Typical cladding materials include brick (which is supported vertically by the foundations and laterally by the structure), cementitious panels applied to rigid insulation, and rainscreen panels attached to sub-framing or directly to the structure.

2 Windows & Doors

Window and door frames are generally fitted into the modular units in the factory and their detailing is similar to other forms of framed construction. The number of openings and area of glazing permitted in any one modular unit is limited only by structural requirements. If large openings are required it may be necessary to incorporate hot rolled steel elements into the structure of the unit. The external cladding must be detailed to fit around the openings with appropriate waterproofing details.

Exterior cladding; The Modules at TempleTown, Lehman Child Care Center, Atlantic Yards B2 tower

Exterior installation; The Stack, New York City; Gluck+

Exterior installation; The Modules at TempleTown; Interface Studio Architects
Vertical Circulation

1. Elevators & Stairs

Elevator shafts and stairs can be configured into modules to suit an individual project. Elevator shafts and stairs can also be site built.

**Integrated stair modules;** DeLuxe Building Systems

**Possible stair and elevator configuration;** Kullman Building Corporation
MEP and Services

1 Decentralized Systems

Decentralized mechanical systems are often used in modular buildings. This eliminates the need for deep ductwork required to transfer conditioned air from a central plant. Decentralizing also avoids some of the complexities of routing the systems and making field connections.

2 Hookups & Distribution

Installation of electrical, plumbing, and heating services in modular buildings can largely be achieved in the factory while final connections are made on-site. A vertical service duct is incorporated in each unit to accommodate vertical drainage and pipework. The services within each unit are installed in the factory and terminate at the vertical duct. Access to the service duct is generally made from corridors outside the unit, which allows services to be connected on-site within the duct and without the need to enter the unit. This minimizes potential damage to the finishes within the apartments. Horizontal distribution is often run through the ceilings of the corridors, which requires a dropped ceiling. Hookups can also be made through removable floor or wall panels.

The corridors within the modular units arrive to the site unfinished so these connections can be made easily. Corridor lighting and finishes are then installed on-site once the services are in place. The design of access points and chase enclosures can be integrated with the building’s finishes.
Interior Finishes

1 Schedule of Completion

The goal of modular construction is to complete as much as possible in the factory setting. However, some finish work always needs to be done on site. This includes the corridors after MEP hook-ups are made, any interior spaces that are built on-site, and the joints between modules. When openings occur at module mate-lines the finishes need to be stitched together in the field. Therefore, designers should pay close attention to detailing these finish transitions at mate-lines. Alternatively, floor finishes can be applied entirely on-site in order to cover the mate-line in the floor seamlessly, though this requires more on-site labor.

2 Quality of Finishes

Quality of finishes are not restricted by modular construction. Any grade of finishes can be selected and installed in the factory by trained craftsman. Finishes in marquee spaces, such as lobbies and amenities, can be installed on-site for greater control and without the need to account for joints at module mate-lines.
Disruptive Application

Modular in DC?
Modular in DC?

Conventional vs Modular

Non-Union vs Union

Wood vs Steel

???????????
Disruptive Application

Multifamily residential construction is currently booming in the national’s capital, but developers have been shy to adopt modular construction techniques. Despite the expedited schedules, higher quality, and environmental benefits of modular, and the successful use of the system in other major cities, there have not yet been any large-scale modular construction projects in Washington, DC. In order to better understand the constraints and challenges, the preceding research has been applied to a speculative design for a real site in the Brookland neighborhood of Washington, DC.

Speculative Project Site

The site is located adjacent to the Brookland-CUA Metro station on the Red Line in the Northeast quadrant of the District of Columbia, and it was included as the south parcel in the Washington Metropolitan Area Transit Authority (WMATA) Joint Development Solicitation that was released in November 2013.

The Brookland-CUA Metro station and WMATA bus loop are immediately to the west of the site. The Metro station’s existing Kiss & Ride facility is located on the site, and the project proposal incorporates a replacement facility on the ground floor. This proposal aims to develop a new multifamily residential building that will offer rental units in a mix of unit sizes from juniors to two bedroom units.
Initial Concept

The initial concept of the application phase of this study was to investigate the use of modular construction to replace wood frame stick-built construction over a concrete podium, which is a common construction type in Washington, DC. The speculative project was therefore assumed to be five stories of wood modular or stick-built construction over a site-built concrete podium. However, after researching the limitations of wood modular and discussing the costs with a local contractor (Davis Construction) it quickly became apparent that wood modular construction would not be competitive in Washington, DC. Below is a list of major factors that drove this decision:

- Wood buildings are limited in height and gross square area by building code
- Wood is less rigid than steel, and thus limits open spans and requires more lateral bracing
- Wood modular requires temporary supports for transit loads
- Wood modular requires a very deep ceiling to floor connection (2’-0” minimum)
- Less work can be done in the factory since wood modules can not support heavy appliances, millwork, and finishes during transit. This reduces the same savings benefit of modular construction.
- The negative market perception of modular construction is more pronounced with wood. Steel modular is generally perceived as higher quality.
- Wood frame stick-built construction is very affordable in the Washington, DC, market. Early pricing studies by Davis Construction have shown that wood modular costs 35% more than conventional wood framing.

*Approximate overall building cost; based on 2013 study by Davis Construction
Comparison

Revised Concept

During early discussions Davis Construction expressed interest in comparing steel modular construction to a conventional cast-in-place concrete building. Using the same site and floor plan as the initial concept, the study was revised to compare nine stories of modular or conventional construction over a site-built concrete podium. We compared both total building cost and construction schedule for both options using both union and non-union labor. All four estimates were then plugged into a pro-forma to compare the project returns for each option. The following pages show an abbreviated set of the basic drawings of a multifamily residential project for the Brookland WMATA site that were used to generate the cost and schedule comparisons, including a floor plan, module plan, sections, a sample unit plan, and a massing study.

Assumptions

The following are the assumptions that were taken into account for the estimates:

• The modular option consists of nine stories of steel modular over a site-built concrete podium.
• The conventional option consists of nine stories of cast-in-place concrete structure over a concrete podium
• The site-built concrete podium is identical for both options and that is assumed to be existing when construction on the upper floors started
• To make this study an apples-to-apples comparison the building form does not take advantage of the interesting architectural opportunities that modular allows. The modular option for this study uses a straightforward stacking approach with some setbacks for balconies. The building skin was assumed to be installed on-site.
Building Section

SITE-BUILT CONCRETE PODIUM

STEEL MODULAR UNITS

Key Plan

East/West Building Section; 1/8" = 1'-0"
Program Elements

The speculative project offers rental units in a mix of unit sizes from juniors to two bedroom units. The proposal will offer affordable units per DC Inclusionary Zoning requirements. The building will strive for LEED certification and feature many sustainable design strategies, such as water-reducing fixtures, energy efficient equipment and lighting, and storm water retention systems.

The building features residential amenities on the second floor that include a Club Room and a Fitness Center, both with access to an amenity roof terrace. The amenity spaces are site-built due to the large spans and irregular room geometry.

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<th>L04</th>
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Typical Floor Plan; 1/8” = 1’-0”
Sample Unit Plan

Sample Junior and 1 Bedroom Unit Layout; 1/4" = 1'-0"
Modularization

UNITs

MODULEs

1/8" = 1'-0"
Modularization

LEGEND
- SITE BUILT PODIUM
- SITE BUILT BELOW GRADE PARKING
- LIVING ROOM MODULE, 12'-6" x 65'-0"
- BEDROOM MODULE, 11'-6" x 65'-0"
- LIVING ROOM MODULE, 12'-6" x 35'-0"
- BEDROOM MODULE, 11'-6" x 35'-0"
- JUNIOR MODULE, 16'-0" x 30'-0"
- MODULES STACK VERTICALLY; DIMENSIONS VARY

*LENGTH DIMENSION IS APPROXIMATE; VARIES AS MODULES SET BACK FOR BALCONIES
Cost/Schedule Analysis

1. How much?

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*Total Building Cost per GSF* includes direct construction cost, union premium, general conditions, contingency, contractor insurance, builders risk insurance, general contractor’s fee, gross receipts tax, performance and payment bond, and escalation. This study assumes that the podium was already built when construction on the tower started.


2. How long?

<table>
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3. Summary

- Modular is $29.48/sf more than conventional when using non-union labor
- Modular is $1.61/sf less than conventional when using union labor
- Modular is 9 weeks faster than conventional when using non-union labor
- Modular is 22 weeks faster than conventional when using union labor
Project Return Analysis

1. Is it worth it?

In order to test the financial feasibility of using modular construction for the speculative project, a local developer (CityInterests) agreed to run several pro-forma models to test the four scenarios priced by Davis Construction.

Through the comparison of several metrics measuring return on investment (equity multiple, IRR, and standardized yield on cost), it becomes clear that modular construction is not competitive against conventional construction built with union labor. However, modular construction produces slightly higher returns when compared with conventional construction built with union labor. Whether or not those returns are high enough to justify the increased risk associated with a new construction type depends on the investor/developer risk appetite. Some owners may be quick to jump at a new potentially ground breaking opportunity with higher risk/reward potential, while others may not be as keen to be first to the party. The decision will also depend on project size, investment requirements, and portfolio size for the individual company assessing the deal.

2. Assumptions

The following are the assumptions that were taken into account for the estimates:

- The project includes 300 units rented at $3.00/sf
- The land acquisition price is $10,000,000
- The construction loan interest rate is 4.50%
- The only variables are the length of construction and the total building cost/gsf

3. Equity Multiple

An equity multiple is a metric that describes the number of times the investor is expected to receive their original investment back over the life of the investment. It does not take into account the time value of money.
Project Return Analysis

4 Internal Rate of Return

An IRR is the interest rate at which the net present value of all the cash flows (both negative and positive) from a project or investment equal zero. An IRR is a valuable metric because it takes into account all cash flows and the time value of money, which thereby provides the investor a benchmark by which it can evaluate competing investments. Unleveraged IRR assesses a project independent of the lending environment (as if it were a cash deal), whereas leveraged IRR accounts for how debt impacts the cash flow (including interest and debt payments).
Project Return Analysis

5 Standardized Yield on Cost

The yield on cost is a measure of cash flow return that measures the net operating income expected to be generated from a development property as a percentage of development cost. Unleveraged yield on cost assesses a project independent of the lending environment (as if it were a cash deal), whereas leveraged yield on cost accounts for how debt impacts the cash flow (including interest and debt payments).
Modular in DC?

Moving Forward

So does it make sense to use modular in Washington, DC? At the time of this writing, the answer is only under certain conditions. The project must be a high-rise that would conventionally be built with cast-in-place concrete, and the project must be built with union labor. The speculative project comparison undertaken through this iLab suggests that increasing modular’s presence in other nearby cities with strong unions, such as Baltimore, may be a better opportunity.

A major challenge in the Washington, DC, market is combatting the negative market perception of modular construction. This is a challenge that architects can help solve by showing clients the unique architectural opportunities and increased construction quality that modular allows. The use of well designed, high quality precedents is important, as is educating clients and the public about modular construction and its benefits. Further developing the Jenga massing studies found in this document would be a worthwhile endeavor to demonstrate the possibilities of expressing the module on a facade. In addition, studying the potential opportunities for unit design may reveal interesting new unit types based around increased terraces and access to individual exterior space for renters. The use of modular construction is increasing in other major cities around the country, and so the future of modular in the nation’s capital is rich with potential.
Advantages

1. Up to 50% reduction in project schedule delivers product to market faster
2. Potential reduction in total project cost when built with union labor; more accurate cost estimating
3. Controlled factory conditions increase the predictability of quality, cost, and time
4. Better construction sequencing and fewer conflicts in crew scheduling
5. Reduces site environmental impacts due to reduced material waste, pollution, dust, and noise
6. Reduces site constraints such as staging, weather, and security

Challenges

1. Increased risk for first project due to uncertainty by lenders
2. Negative market perception that modular construction is cheap, ugly, and of inferior quality
3. Cost savings is not as big in Washington, DC, as in other major cities due to lower labor rates
4. Must recognize the nature of modular buildings and their constraints during the design process
5. Alters traditional design/documentation process and financing structure
Resources & Credits
Bibliography


Illustration Credits

Illustration Credits

34. “Figure 2.4.1: Longitudinal section showing typical opening.” Modular Architecture Manual. Page 39.
35. “Figure 2.4.2: Longitudinal section showing clear span.” Modular Architecture Manual. Page 39.
36. “Figure 2.4.4: Cross section showing clear span.” Modular Architecture Manual. Page 39.
38. “Figure 3.5: Compartment floor at junction with external wall and compartment wall.” Modular Construction using Light Steel Framing: Design of Residential Buildings (SCI Publication P302). Page 37.
39. “Figure 2.4.6: Typical plan detail.” Modular Architecture Manual. Page 41.
40. “Figure 2.4.7: Typical section detail.” Modular Architecture Manual. Page 41.
41. “Figure 2.4.8: Typical Mate-line section detail.” Modular Architecture Manual. Page 43.
53. “Figure 2.4.10: Foundation detail.” Modular Architecture Manual. Page 45.
54. “Figure 2.4.11: Piloti foundation.” Modular Architecture Manual. Page 45.
55. “Figure 2.4.12: Perimeter basement foundation.” Modular Architecture Manual. Page 45.
Illustration Credits

57. “Figure 3.2.7: 75 ton luffing jib crane, commonly used in modular construction.” Modular Architecture Manual. Page 65.

58. “Figure 5.3: Various methods of lifting modular units.” Modular Construction using Light Steel Framing: Design of Residential Buildings (SCI Publication P302). Page 75.

59. “Figure 3.2.1: Craning site plan: Pierson College, New Haven, CT.” Modular Architecture Manual. Page 60.


62. “Figure 3.2.12: Blind rivet section.” Modular Architecture Manual. Page 68.

63. “Figure 3.2.11: Setting pin section.” Modular Architecture Manual. Page 68.

64. “Figure 3.2.12: Setting pin identification, underside of module.” Modular Architecture Manual. Page 68.

65. “Figure 3.2.14: Stacking of modules.” Modular Architecture Manual. Page 68.

66. “Figure 3.2.15: Fastening of modules.” Modular Architecture Manual. Page 68.

67. “Figure 2.4.9: Roof Types.” Modular Architecture Manual. Page 44.


74. “Figure 2.4.14: Possible stair configuration (facing wall removed for clarity). Modular Architecture Manual. Page 47.

75. “Figure 2.4.13: Possible elevator configuration. Modular Architecture Manual. Page 46.


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