MULTIFAMILY, MID-RISE BUILDINGS USING WOOD CONSTRUCTION

A COST-EFFECTIVE AND SUSTAINABLE CHOICE FOR ACHIEVING HIGH-PERFORMANCE GOALS

Presented by:

THINK WOOD®

WREN
Location: Los Angeles, CA
Architect: Togawa Smith Martin

The $144 million WREN multifamily project in L.A.'s fast-rising South Park district helped to rewrite a neighborhood's narrative through thoughtful innovation, commercial discipline, and the magic of a remarkably nimble building material … wood. The glittering pair of seven-story buildings transform the skyline along Pico Boulevard through a series of innovations, including the city's first Type III double-podium design. The challenge for wood framed buildings in high seismic zones is how to provide large glass areas and still provide sufficient shear walls. To achieve this, the team worked with the structural engineer to determine the minimal length of shear wall required at each floor. Any area not required for shear wall was used for windows. The structural characteristics of wood were blended to create an aesthetically pleasing open grid on the exterior of the building. Photo: Kevin Korczyk / Jeremy Samuelson

LEARNING OBJECTIVES

Upon completion of this course the student will be able to:

1. Identify the sustainability and economic benefits of using wood construction for mid-rise multifamily or mixed use buildings
2. Summarize building code requirements and provisions for mid-rise multifamily wood-frame structures
3. Discuss wood framing solutions that address issues such as shrinkage, fire protection, and seismic requirements while minimizing the carbon footprint of the building
4. Explore innovations in wood framing design techniques and wood product technologies that enhance energy efficiency

CONTINUING EDUCATION

AIA CREDIT: 1 LU/HSW
GBCI CREDIT: 1 CE HOUR

AIA COURSE NUMBER: AR092017-3

GBCI COURSE NUMBER: 920013097

Use the learning objectives above to focus your study as you read this article. To earn credit and obtain a certificate of completion, visit http://go.hw.net/AR092017-3 and complete the quiz for free as you read this article. If you are new to Hanley Wood University, create a free learner account; returning users log in as usual.

Multifamily housing has been, and continues to be, a very active part of design and construction activity across the United States. In many settings, that involves multi-story buildings containing apartments, condominiums or co-op units designed to meet the needs of a broad community or specific lifestyle. It can also include other particular residential uses such as dormitories, convents, long term stay hotels and motels, or vacation timeshare properties. In all of these cases, one of the most fundamental decisions facing a design team is what structural materials to construct the building out of. Steel, concrete, and masonry typically come to mind, but in recent years wood construction of various types has become quite popular and preferred.

While commonly thought of for single family residential construction, the cost-effective, code-compliant, and sustainable attributes of wood construction carry over to mid-rise multifamily projects too. In this article we will look at some of the reasons for the rising popularity of wood in multifamily buildings, review code compliance and fire safety technical considerations, and discuss techniques for successful wood building designs. In addition we'll address two trends that are expanding the opportunities for wood use in multifamily, multi-story design.

WHY WOOD?

Developers and design professionals have recognized wood construction as a way to effectively achieve higher density housing at a lower cost, all while reducing the carbon footprint of their projects. Here are few experiences of architects who have completed some successful multifamily projects using wood construction.

Cost Savings

Among their benefits, wood buildings typically offer faster construction and reduced project first costs. For example, after completing the first phase of a developer-funded five-story student housing project using steel construction, OKW Architects in Chicago switched to wood. "The 12-gauge steel panels used in the first phase were expensive, very

Source: American Wood Council

Residential

Permanent stay multiple-family facilities (R-2) and Transient (R-1)

(i.e., apartments, convents, dormitories, fraternities and sororities for R-2; hotels and motels for R-1)

NFPA 13 Sprinklers

100% Open Perimeter

	Type IIIA	Type IIIB	Type VA	Type VB
Maximum stories	5	5	4	3
Maximum building height (ft)	85	75	70	60
Total building area (at maximum permitted stories) (ft^2)	270,000	180,000	135,000	78,750
Total building area (ft^2), single-story building	114,000	76,000	57,000	33,250
Total building area (ft^2), two-story building	180,000	120,000	90,000	52,500

IBC maximum allowable heights and areas for residential wood construction

CASE STUDY: MULTIFAMILY DEVELOPMENT HOME RUN

2016 Wood Design Award Winner: Brooklyn Riverside, Jacksonville, Florida. Architect: Dwell Design Studio. Photo: Pollack Shores, Matrix Residential

Project: The Brooklyn Riverside

Location: Jacksonville, FL

Architect: Dwell Design Studio

Award category: Regional Excellence

Completed in 2015 for a construction cost of $24 million, The Brooklyn Riverside consists of seven Type VA multi-residential buildings, with a total of 310 units and 77 private tuck-under garages. Density was an important design objective, and the use of automated sprinklers as well as significant open frontage and parking allowed the design team to add another level and thus increase the number of units. The project also includes a 2,200-sf clubroom, leasing office, fitness center, gaming center, pool, and amenity deck, which features a covered bar and lounge. Given the project location, moisture management was a key design consideration. Among the team's strategies, wood structural sheathing panel was used as an exterior applied air barrier, breezeway entries and garage slabs are dropped 6" from adjacent finished floors and slope toward the exterior, and perimeter isolation strips are used within each unit, between the gypcrete, wall finish, and baseplate.

heavy and difficult to install; and welding and screwing the shear strap bracing was very time consuming," says project architect Eileen Schoeb. "Using wood was far more economical for the second phase."

Similarly, for the three-building, five-story Berkshire Terminus (formerly Crescent Terminus) development in Atlanta's upscale Buckhead district, wood framing helped to achieve overall budget goals. Architect Erik Brock of Lord Aeck Sargent noted, "From a design standpoint, we were able to use wood to introduce a fresh, contemporary aesthetic to a mid-rise multi-level development. By saving on the framing and speed of construction, Crescent Communities was able to deliver a higher-quality finished product for their tenants by putting more into the amenity package, landscaping, finishes and overall character of the residential units." Note that Crescent Communities was the developer, hence the original building name Crescent Terminus, but the property was subsequently bought by an affiliate of Boston-based Berkshire Group, and the name was changed to Berkshire Terminus.

Code Compliant, Marketable Structures

Many design professionals who are familiar with wood construction for two- to four-story residential structures are not aware that the International Building Code (IBC) allows five stories of wood-frame construction in many residential building occupancies and six stories for business occupancies. Five-story wood buildings are increasingly common, but some designers used to other materials still aren't aware that the International Building Code (IBC) allows five stories of wood-frame construction for most occupancies—including multi-family, military, senior, student and affordable housing—and six for business. "Wood buildings are quality buildings, and they're safe buildings," said Lisa Podesto, PE, Senior Technical Director with WoodWorks-Wood Products Council. "Building codes are meant to be material neutral, which means that a midrise wood-frame building is required to meet all of the same safety and performance requirements as a similar building made from any other material. Once building owners and designers have that awareness, one of the most compelling reasons to use wood is cost. Wood buildings tend to offer a high percentage of rentable square footage at a relatively low cost—which helps developers maximize the value of their projects. Wood's aesthetic, versatility and sustainability also make it the most desirable choice for many design teams."

When asked how building with wood fits into Crescent Communities' mission of quality, Jared Ford, Senior Vice President cites design flexibility. "With concrete, you can't easily design to have the building pop in and out to create the architectural reveals the way you can with a wood-frame building. We can do a lot more design-wise with wood that we couldn't do with other products. So both our design goals and our commitment to the environment provided the motivation for Crescent Terminus to be a wood-frame building."

Sustainability

Wood construction offers advantages for project teams seeking green building certification or simply to reduce the environmental impact of their buildings. Wood grows naturally and is renewable, and life cycle assessment studies consistently show that wood offers environmental advantages in terms of embodied energy, air pollution, water pollution, and other impact indicators.[1]

CASE STUDY: LUXURY AND PERFORMANCE

Berkshire Terminus, Atlanta, Georgia. Architect: Lord Aeck
Photo: Richard Lubrant

Project: Berkshire Terminus

Location: Atlanta, Georgia

Architect: Lord Aeck Sargent

Year of completion: 2014

Surrounded by high-rises, Berkshire Terminus consists of three luxury apartment buildings, each with three levels of parking topped with five stories of wood-frame construction.

"This land was at a cost basis that is among the highest in our portfolio," says Jared Ford, Senior Vice President for Crescent Communities. "It's prime real estate, but that's where the market is. We're either building or hunting in 13 of the top 20 metropolitan markets, and we're almost entirely focused on wood-frame multi-family apartments."

As with any complex project, there were a number of design challenges. For example, to maintain the integrity of the fire rating of the exterior bearing walls, the team used top-chord bearing trusses for the floor framing. To minimize shrinkage, techniques included using engineered wood for the plates and blocking in the first two floors, and larger sealant joints around windows and doors to allow movement. The team also designed stairs with double stud walls to provide a 2-hour fire separation, specified concrete block construction at the elevator shaft, and used a wood-frame wall to separate the elevator shaft from the rest of the construction.

From a carbon footprint perspective, wood continues to store carbon absorbed during the tree's growing cycle, keeping it out of the atmosphere for the lifetime of the building—or longer if the wood is reclaimed at the end of the building's service life and reused or manufactured into other products. The manufacturing of wood products also results in less greenhouse gas emissions than other materials.[2] For example, the Berkshire Terminus development in Atlanta includes three buildings, each with five stories of wood- frame construction over a concrete podium. Using the online Wood Carbon Calculator for Buildings[3], the project has been shown to store and avoid the equivalent to 13,523 metric tons of CO2. The U.S. Environmental Protection Agency's Greenhouse Gas Equivalencies Calculator identified that this equates to emissions from 2,583 cars in a year.

In terms of long term durability and life cycle, a survey of 227 buildings demolished in Minneapolis/St. Paul found that buildings are often torn down within 50 years. This was true regardless of construction materials, and was instead more commonly due to the changing building needs and increasing land values as opposed to material performance issues.[4] Overall, wood buildings in the study had the longest life spans, showing that wood structural systems are fully capable of meeting a building's longevity expectations. In addition, when the embodied energy in demolished buildings is considered along with the implications of material disposal it is clear that longer lasting buildings are more sustainable. Further, the fact that wood can be reused at the end of its service life in a building, either through renovation or deconstruction and reuse (with minimal additional processing) is a significant advantage.

THE BUILDING CODE AND WOOD CONSTRUCTION

As with any type of construction, mastering the technical details of wood-frame construction is critical to creating cost-effective buildings that are durable, safe, and code compliant. Building codes require all building systems to perform to the same level of safety, regardless of material used, and wood-frame structures can be designed to meet or exceed standards for (among other things) fire protection, seismic performance, and resistance to high winds. The International Building Code (IBC) is the predominant model building code in the United States, having been adopted by most jurisdictions with or without amendments. It is reviewed and/or amended over a three year cycle with the 2015 edition being the latest version and the one that will be referenced throughout this article. (Note that for specific projects in specific locations, other versions may be in effect such as the 2012 edition.) Some specific, relevant items are addressed as follows.

Construction Types

Chapter 6 of the IBC categorizes buildings into five distinct types of construction. Each building type is further subdivided into A and B sub-types with A indicating higher fire resistance ratings than B.

- Construction Types I and II are generally limited to non-combustible materials such as concrete and steel for structural and some non-structural items. Wood is an allowable material in nonbearing walls and partitions that do not require a fire rating.
- Type III is defined as noncombustible exterior walls and interior walls of any material allowed by code. Fire-retardant-treated wood framing is allowed per the provisions of the code for exterior wall assemblies of a 2-hour rating or less.
- Type IV is also known as Heavy Timber (HT) and also requires noncombustible exterior walls. Interior building elements are defined as made from solid or laminated wood without concealed spaces. The IBC elaborates on different types of solid and laminated wood products and requirements for each. This construction type has received a lot of attention lately due to its growing use in multi-story buildings of all types, including multifamily.
- Type V allows structural elements, exterior walls, and interior walls to be constructed of any material allowed by code including common wood framing systems.

Tim Smith, AIA, is a founding principal of Togawa Smith Martin, Inc. in Los Angeles, and a pioneer of five-story wood framing in California. He has looked carefully at the appropriate use of each of these five construction types and notes that, "From a cost perspective it makes no sense to use Type I for five stories. Type I is more realistic for taller buildings. Type III using wood construction helps fill the gap between low-rise and taller buildings."

Permissible Increases in Area and Height

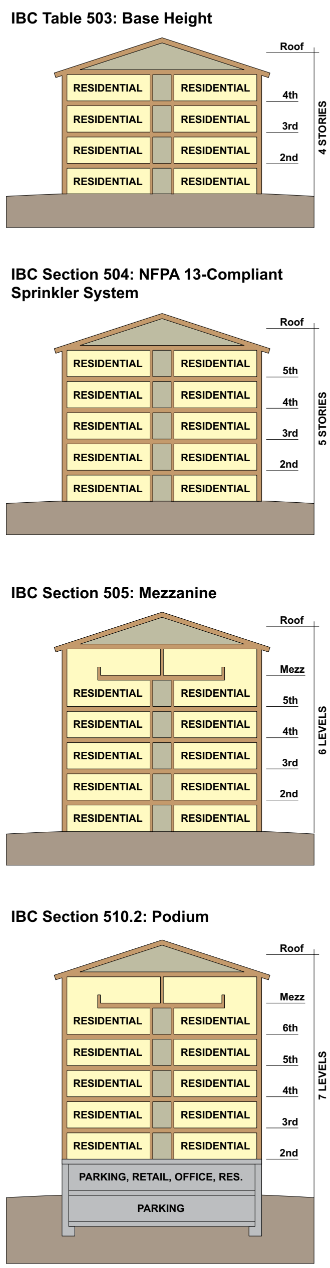
Chapter 5 of the IBC addresses "General Building Heights and Areas." There are several considerations here:

- **Allowable heights** are determined based on occupancy classification and construction type as shown in Table 504.3. Multifamily buildings (R Occupancy) with no sprinklers and built with Type III, IV or V construction are allowed to be between 40 and 65 feet tall depending on Type and subtype (A or B). However, virtually all new R Occupancy multifamily buildings must now have fire sprinklers under Chapter 9 of the code. Therefore, new multifamily buildings with sprinklers can be up to 60 feet tall if a sprinkler system in accordance with NFPA Standard 13R is installed. If a sprinkler system is installed per the broader NFPA Standard 13 then the allowable height can be increased up to 70, 75, or 85 feet depending on the construction type.

- **The number of stories** is treated separately from building height, meaning that both must be complied with. The code limits the number of stories above the grade plane based on occupancy and construction type. Hence, multifamily R-1, R-2, R-3, and R-4 occupancies can be limited to between 2 and 5 stories depending on construction type and sprinkler system type. So, for example, an R-2 apartment building with an NFPA 13R sprinkler system with Type V-A, IV or III construction is allowed to be 4 stories tall. If the sprinkler system is changed to a general NFPA 13 system, then Type II, III, and IV construction is all allowed to go to 5 stories.
- **Mezzanines** are not considered stories under the code. Rather, they are defined as intermediate levels between the floor and ceiling of a story and are considered to be part of the story below the mezzanine. Mezzanines can be inserted into stories as long as their floor area falls within code area limits and the total allowable building height is not exceeded.
- **Floor areas** for fire separation purposes are defined in the code again based on occupancy, sprinkler type and construction type. For multifamily projects that allowable area can vary widely based on these variables. For example, an R-2 apartment building with an NFPA 13R sprinkler system and Type V-B construction is limited to 7,000 square feet, which may be fine for many situations. But if larger floor areas are sought, then switching to a standard NFPA 13 system would allow an increase to 21,000 square feet for a multi-story building compared to changing to Type V-A construction which would only allow up to 12,000 square feet. By contrast, keeping the NFPA 13R sprinklers and going to Type IV (HT) construction would increase the allowable area up to 20,500 square feet compared to Type III-B at 16,000 square feet and III-A at 24,000 square feet. Switching to the standard NFPA 13 sprinkler system would triple each of those allowable areas.
- **Open front areas** are defined in the IBC in Section 506.3 as a means to allow increases to the floor areas above based on open access of at least 25 percent of the building façade onto a public area at least 20 feet deep. The amount of the increase can be calculated based on formulas found in this section.

"Type IIIA construction for Residential Group R is permitted to be four stories and 65 feet high while a Type VA building is permitted to be three stories and 50 feet," explains WoodWorks' Podesto. "However, when protected with NFPA-compliant automatic sprinklers, Type IIIA and Type VA buildings are allowed to be five and four stories, respectively. Type IIIA is permitted an increase in height to 85 feet and Type VA an increase to 70 feet." (See Table of IBC Allowable Heights and Areas for Residential Construction.)

Permissible increases in height and area under the 2015 IBC



Source: Togawa Smith Martin

FIRE PROTECTION REQUIREMENTS

All buildings, including multifamily buildings, need to protect the health, safety, and welfare of its occupants, especially from the threat of fire. The code recognizes that there are many different ways to do that and requires that the design professional demonstrates that minimal levels of fire protection are provided. Such minimum fire-resistance rating requirements for building elements, (i.e. structure, walls, floor, roof, etc.) based on construction type are provided in IBC Table 601. Specific details of fire and smoke protection features are detailed in Chapter 7. The intent is that the combination of materials provides containment of a fire within a defined space (such as an apartment) so that others in the building have plenty of time to leave before there is any threat of a fire moving on to other parts of the building.

Based on these requirements wood-frame building elements, just like other materials that require fire resistance ratings, often show compliance per independent test procedures. Two common testing standards are ASTM E119, "Standard Test Methods for Fire Tests of Building Construction Materials" or UL 263 "Fire Tests of Building Construction and Materials." The code also provides alternative methods for determining fire resistance per IBC Section 703.3, which includes prescriptive fire resistance as shown in tables in Section 721.

Fire Separations

There are several ways that the code acknowledges a design that separates out sections of the building to create contained fire areas.

- **Fire Walls**

  IBC Section 706 specifically addresses Fire Walls and permits portions of a building separated by one or more of them to be considered as separate, side-by-side buildings. In this way, wood-frame buildings can be designed as separate but connected buildings for code-compliance purposes. This partitioning allows wood buildings to be unlimited in size.

- **Podium Design**

  In multi-level wood-frame buildings, architects and engineers are increasingly turning to podium or pedestal design instead of building directly on a concrete slab on grade. This can effectively add another floor level to the maximum permissible number of stories. Section 510 of the IBC addresses Special Provisions and allows five- or six-story wood-frame structures over one level of Type IA construction. These "five-over-one" and "six-over-one" buildings are treated in the code as two structures separated by a three-hour fire-resistance-rated horizontal assembly.

  The podium is considered as a separate and distinct building for the purpose of determining height and area limitations and vertical continuity of fire walls. The overall height of the two buildings together is measured from grade plane, and the height limitations of Chapter 5 apply.

Fire-Resistance Assemblies

One-hour and two-hour fire-resistance requirements are generally met by using assemblies of products and materials, commonly including gypsum sheathing over wood. Lists of accepted rated wood floor and wall assemblies are available from the American Wood Council (DCA 3: Fire-Rated Wood-Frame Wall and Floor/Ceiling Assemblies, www.awc.org) and the APA – the Engineered Wood Association (Form W305, www.apawood.org). Other sources include Underwriter's Laboratories (UL) fire-resistance-rated systems and products, the UL Fire Resistance Directory, and the Gypsum Association's Fire Resistance Design Manual.

Fire Resistance of Heavy Timber

Part of the reason heavy timber is effective is that it takes a long time to burn through it. That means that heavy timbers have a particular advantage in a fire because they char on the outside while retaining strength, slowing combustion and allowing time for occupants to evacuate the building. The sizing of the heavy timbers is addressed in the code to allow for a structural safety factor to be built in. This allows a defined percentage to be allowed to burn or char in a fire knowing that the structural integrity still remains.

Fire Retardant-Treated Wood (FRT)

The building code (IBC Section 2303.2) permits exterior two-hour rated bearing walls in Type III construction to be constructed of fire retardant-treated (FRT) wood, an acceptable substitute for a non-combustible material.

Designing for Different Adjacent Fire Ratings

One design consideration for some construction types is that floors and walls may have different fire rating requirements. For example, in Type IIIA construction, load bearing exterior walls are required to have a two-hour rating but a floor may only require a one-hour rating. The detailing to achieve this smoothly and effectively is important for a good design. It can be accomplished by allowing the wall studs with one layer of gypsum to extend up to the underside of the floor sheathing past the floor framing. The framing can then be supported off of the top wall plates with the use of a hanger designed to span over a layer of gypsum sheathing. Another framing option is to hang the floor framing off a 2x ledger, which provides as much if not more fire resistance as the layer of gypsum. The one-hour wall rating plus the one-hour floor system yields the required two-hour rating. Designers should work with their local building official to determine an acceptable solution to fire-resistance detailing at the floor-to-wall intersection as the code is silent in this area.

DESIGN CONSIDERATIONS FOR FRAMING WITH WOOD

Traditional practices and code provisions for wood framing are fairly well known and established such that wood framing options and details are readily available for designers to incorporate. Chapters 16, 17 and 23 of the IBC cover structural wood design and construction techniques in considerable detail making it rather straightforward to work with. However, in addition to selecting the appropriate framing technique, designers of wood buildings must consider factors such as shrinkage, differential movement, and seismic requirements.

Platform Framing and Balloon Framing

There are three common types of framing for wood construction. For Type VA buildings, where exterior walls require a one-hour fire-resistance rating, traditional platform framing is usually used, where the joists sit on top of the double top plates of the wall. Balloon framing is based on the joists hanging off a ledger that is attached to the structural studs that frame the building. In modified or semi-balloon framing, the floor framing hangs off double top plates; it is often used as an alternative to platform-framed structures for both Type VA and Type IIIA construction.

Wood Shrinkage

Regardless of the framing type, IBC Section 2304.3.3 requires that designs for buildings over three stories take into account the fact that wood shrinks as it dries. Shrinkage continues until wood reaches its Equilibrium Moisture Content (EMC), which averages 8 to 12 percent moisture content for most structures in the U.S. "WoodWorks provides free project support for wood buildings and addressing shrinkage is one of the topics we get asked about the most," said Podesto. "It can seem daunting, but there are several approaches, all of which involve simple calculations. It also helps to understand how and why wood shrinks, use care when selecting and specifying materials and details,

Fire-resistance requirements for Type IIIA and Type VA construction

*Source: IBC Table 601, **IBC Table 706.4

	Exterior Bearing Walls*	Interior Bearing Walls*	Floor Construction*	Roof Construction*	Fire Walls**
Type IIIA	2 hrs	1 hr	1 hr	1 hr	3 hrs (most occupancies)
Type VA	1 hr	1 hr	1 hr	1 hr	2 hrs

FIRE SAFETY DURING CONSTRUCTION

Although less than 2 percent of building fires occur during construction, this phase presents unique risk scenarios that make any building more vulnerable regardless of material.

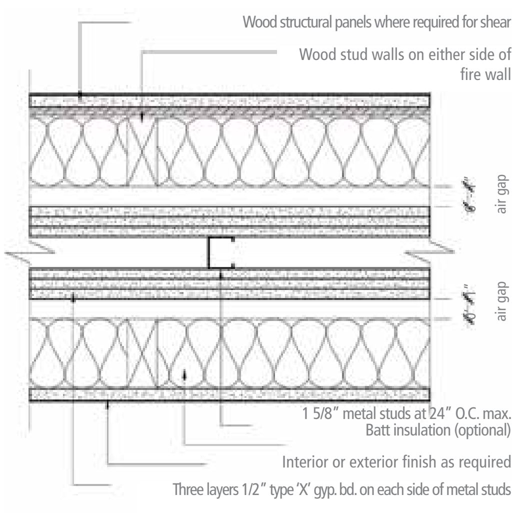
IBC Chapter 33 provides minimum safety precautions for fire during construction and the protection of adjacent public and private properties. The section includes provisions for fire extinguishers, standpipes, means of egress and sprinkler system commissioning. The International Fire Code also contains detailed requirements.

The most common causes of fire in wood buildings under construction are arson and hot work, making site security, rigorous procedures for workers, and access to fire hydrants a must. Education is also important, since fires that occur during this phase are also caused when required elements—such as fire doors, smoke alarms, and sprinklers—have not been put in place.

and make sure materials are properly cared for and installed. And if you're still unsure—give your local WoodWorks rep a call or email the help desk and we'll walk you through it." www.woodworks.org / help@woodworks.org The shrinkage effects must be considered for horizontal framing members (width or thickness) in the wall (top/sill plates) and floor (joists) design. Wood is anisotropic, meaning the dimensional change in wood is unequal in different directions. In most softwoods, radial shrinkage (across growth rings) is approximately 4 percent and tangential shrinkage (parallel to growth rings) is approximately 8 percent from green (unseasoned) to typical EMC for structures in the U.S. Longitudinal shrinkage (parallel-to-grain) for vertical framing members is generally negligible and does not affect building performance. Therefore, the majority of shrinkage will occur in the top plates, sill plate and sole plates, and possibly the floor joists—depending on how the floor framing members are framed to the wall. If the framing is balloon-framed or modified balloon-framed, then sawn lumber joists won't play a huge role in overall movement from shrinkage because balloon framing, unlike platform framing, does not accumulate shrinkage over all floors.

Initial MC, or MC at the time of manufacture, is typically specified on a project's structural drawings. In many parts of the country, the specification would read "a maximum MC of 19 percent." To achieve this, lumber is generally kiln dried. Although there are regional variations, less commonly used green lumber (which typically hasn't been kiln dried and has a

Image: Togawa Smith Martin



Three hours per UL Design No. U435

MC above 19 percent), surface dried lumber or KD-15 (i.e., kiln dried lumber with a maximum MC of 15 percent at time of manufacture) may also be specified. The American Softwood Lumber Standard, PS 20-15, defines dry lumber as "lumber of less than nominal 5-inch thickness which has been seasoned or dried to a maximum moisture content of 19 percent." Ways to minimize shrinkage include (among others) specifying kiln dried lumber, letting the wood dry during construction before closing in the walls, and using products and systems such as pre-engineered metal-plate connected wood trusses for floor and/or roof framing, and manufactured wood products (laminated veneer

PODIUMS-AN ALL-WOOD SOLUTION

Although a podium structure typically refers to wood-frame construction over concrete, a handful of designers have lowered their costs even further by designing the podium in wood.

When determining the cost of a structure, there are a lot variables, including most notably time, materials, and labor. Using wood instead of concrete lowers the mass of the building, which results in more economical podium shear walls and foundations. Using the same material for the entire structure may also mean lower design costs, and the construction team experiences savings in the form of fewer trades on site, which means less mobilization time, greater efficiency because framing is repeated on all of the levels, easier field modifications, and a faster schedule.

Architect Dan Withee, AIA, LEED AP, of Withee Malcolm Architects designed an 85-unit wood podium project in San Diego. He estimated that a concrete podium can cost $15,000 per parking space compared to $9,500 for an all-wood solution.[5]

lumber, I-joists, etc.). I-joist floor systems are dimensionally stable and offer minimal inter-floor shrinkage.

Additionally, there can be some overall settlement of the building that may occur due to gaps in the building construction that can contribute to the overall vertical movement. Some contractors will distribute the dead load throughout the height of the building and allow the building to acclimate to the environment and/or air dry prior to installation of the drywall, thus allowing the building to naturally settle.

Differential Movement

Allowing for differential movement between wood and other structural elements and building finishes is critical. Steel, concrete and brick continue to expand and contract due to temperature changes, while wood generally maintains its dimensions having reached its EMC. Differential movement occurs when, for example, floor joists are supported by a wood-frame wall at one end and by the masonry block of an elevator shaft at the other end. Areas such as stairwells, shafts and vaulted ceilings require attention for differential movements as do plumbing, electrical and mechanical systems. Using flexible joints such as flexible pipe, conduit, couplings, elbows, and tees for electrical, mechanical, and plumbing between floors can prevent potential problems. The design of the joints between building envelope components, such as windows and doors, must also allow for differential shrinkage.

Seismic Requirements

Earthquakes and rigorous seismic requirements are a well-known aspect of building on the west coast, but other parts of the country, especially in the east, are not immune to earthquake activity and the need to comply with seismic codes. Wood construction provides high strength with relatively low weight, and the high strength-to-weight ratio makes wood a good choice for earthquake-resistant construction.[6,7] In wood-frame buildings, the large number of walls and floors often used in a project transfer lateral loads induced by winds and seismic forces.

Wood-frame construction also provides numerous load paths through shear walls and diaphragms, which typically have hundreds of structural elements and thousands of nail connections, adding ductility and redundancy to the system. Redundant load paths give additional assurance that loads will be

CASE STUDY: THE CASE FOR CLT CONSTRUCTION

Candlewood Suites at Redstone Arsenal, Redstone Arsenal, Alabama.

Project: Candlewood Suites At Redstone Arsenal

Location: Redstone Arsenal, AL

Architect: Leidos, St. Paul, MN

Completed: December 2015

From the outside, it looks similar to the thousands of other hotels built across the country in 2015. But when you learn that this project was completed 37 percent faster and the structure built with 44 percent fewer person hours than similar hotels, it warrants a closer look. Developer Lendlease used cross-laminated timber (CLT) to build the four-story, 62,688-square-foot Candlewood Suites® hotel at Redstone Arsenal, a U.S. Army post near Huntsville, Alabama. Completed in December 2015, the project exemplifies one of the biggest benefits of CLT—construction efficiency.

transferred should a connection fail. In contrast, structures supported by heavy non-wood frames have relatively few structural members and connections, meaning fewer load paths.

Moreover, the large number of walls reduces the loads shared by each wall. Tests and observations from past earthquakes show that wood buildings have performed well. For example, a six-story light-frame wood building tested on the world's largest shake table in Japan resisted a major 2,500-year earthquake with minimal damage.

Current building code requirements for wood diaphragms, shear walls, and holdown devices work effectively in creating earthquake-resistive structures. Horizontal diaphragms in roofs and floors transfer the horizontal forces to the shear walls. Shear walls with holdowns such as a continuous tie-down rod system resist the tension forces in an overturning scenario, while wood studs or columns absorb the compression forces.

Wood structural panel shear walls are typically used throughout the building to provide vertical lateral resistance.

Acoustical Control

As with any issue of building performance, the acoustics of a mixed-use and multifamily wood framed building can be designed to meet or exceed minimal requirements, depending on the expectations of the developer, buyers and tenants.

For wall systems, sound isolation can be accomplished in two ways. One is to use partitions with a high mass (75 pounds per square foot, psf, or greater) or to use low mass systems (2 to 5 psf) separated by air spaces of 3 to 6 inches. The goal in party walls or exterior walls is to keep other people's noise out of the living unit, while keeping tenant noise in. In lightweight wood structures, this is achieved by separating the materials with an air space (e.g., stud or joist construction). In terms of acoustical performance, the most effective wood-frame wall is a double stud wall, followed by staggered stud and then single stud.

In mid-rise wood-frame buildings, some options for improving acoustic performance include:

- **Sheathing**

  The mass of the sheathing is just as important as the air space provided by the stud or joist cavity. In acoustical detailing, 5/8-inch-thick type "X" gypsum board is typically required.

- **Insulation**

  The most cost-effective acoustical improvement to a sound isolation system is the addition of batt insulation or any open cell foam system to the stud or joist cavity. While closed cell spray foams have higher R-values and offer improved building envelope energy performance by sealing the partition and improving air tightness, the closed cells do not allow the vibrating air molecules to interact with the insulation product so the sound attenuation is less. It is this interaction that helps reduce the sound.

- **Resilient channels**

  When double or staggered stud construction is not possible, decoupling the sheathing from the framing provides a similar form of isolation.

- **Floor finishes**

  Impact noise can be reduced considerably with the use of soft finishes such as carpet. When carpeting is not practical or desired, coating wood or tile floor systems offer the next best solution.

For a more detailed introduction to these concepts, a technical paper, Acoustical Considerations for Mixed-Use Wood-Frame Buildings, is available at www.woodworks.org/wp-content/uploads/Acoustics_Solutions_Paper.pdf.

DESIGNING WITH INNOVATIVE WOOD PRODUCTS AND BUILDING SYSTEMS

Beyond conventional framing, there are a number of innovative technologies and building systems that are increasing the opportunities for multifamily wood buildings. Some examples follow below.

Prefabricated Systems

Specifying prefabricated or factory manufactured wall and roof panels can provide better quality wall construction since the panels are constructed off-site in moisture controlled environments. Wall panelizing is particularly useful for jobsites that don't have adequate space to construct the walls and can speed the erection time considerably. Wall panels can also optimize stud design and increase sound proofing and energy efficiency. Panels may range from 4 to 30 feet long, and are lifted into place by a crane.

Mass Timber

While traditional wood-frame construction is a proven solution for mid-rise structures up to six stories, mass timber products such as cross laminated timber (CLT) are creating new

Photo: KC Kim, GB Construction

possibilities. CLT is a multi-layer wood panel in which each layer is oriented crosswise to its adjacent layer for increased dimensional stability and structural performance. Widely used in Europe and now available in North America, it is considered viable for buildings up to 12 stories and even higher.

In Australia, CLT has been used to create a 10-story all-wood building, while eight-story examples exist in the U.K. and Austria. North American applications include (among others) a two-story elementary school in West Virginia, a six-story CLT structure in Quebec, a five-story heavy timber/CLT hybrid building at the University of British Columbia, and an eight-level heavy timber/CLT hybrid (six stories plus a penthouse and mezzanine), also in British Columbia.

Among CLT's attractive structural characteristics are high dimensional stability, high axial load capacity, high shear strength, rigidity around openings, and negligible settlement effects. CLT assemblies also offer inherent fire resistance due to thick cross-sections that, when exposed to fire, char at a slow and predictable rate. The industry is also conducting research on the ability of CLT structures to resist lateral loads caused by earthquakes or high winds. Other benefits include speed of construction, thermal performance, and the environmental advantages offered by all wood products—including a low carbon footprint.[8]

The 2015 IBC identifies CLT as a structural product and recognizes it for use in Type IV exterior walls, floors, and roofs. The 2015 National Design Specification® (NDS®) for Wood Construction, referenced in the 2015 IBC, also includes new structural and re-design provisions for CLT.

Plumbing joints with pipes nested in joint to allow for vertical movement of structure

Plumbing sleeve connected to structure with foam wrap to allow vertical movement of structure

CONCLUSION

The last few years have seen a trend toward taller wood buildings, driven by their acceptance in building codes and the value they provide. Design professionals are capitalizing on wood's ability to offer high density at a cost that is typically less than other materials. They also recognize that wood can provide versatility in design that helps with projects focused on affordable urban in-fill and urban/walkable community projects. Building with wood achieves efficiencies that help developers provide more amenities, commonly found in higher-end projects. Wood is also recognized as a renewable and energy-efficient material helping with LEED certification and sustainability overall. Since current building codes recognize the inherent safety and performance capabilities of wood in multifamily buildings, innovative technologies and products can be expected to propel designers to even greater heights on current projects. ■

CASE STUDY: ENGINEERING CITY LIVING

N-Habit Belltown, Portland, Oregon. Architect: Bushnaq Studio, LLC. Photo: Lifestring Photography

Project: N-Habit Belltown

Location: Seattle, WA

Architect: Bushnaq Studio, LLC

Completed: June 2014

Developers responded to Seattle's growing need for affordable housing by building this 49-unit multi-family project at a cost-effective price with wood-framed modular construction. Using this highly efficient construction process, builders took prefabricated, stackable modular living units, built with wood at an off-site location, and assembled them quickly and efficiently on site. The process shortened the construction schedule for this 49,925-square-foot project to just two weekends. Off-site fabrication also contributed to construction quality; each N-Habit module unit was manufactured in a controlled factory environment, which protected interior finishes from weathering. Fire retardant-treated Douglas-fir framing was used in the exterior wall assemblies, which provided an economical structural solution to meet the Type III construction requirements. The project includes five stories of wood-frame modular units above a two-story concrete podium.

CASE STUDY: MASS TIMBER APPEAL

Project: One North—The Radiator Building

Location: Portland, OR

Architect: PATH Architecture

2016 Wood Design Award Winner

The Radiator is a five-story mixed-use office building, with office spaces on floors 2 through 4, and an office with roof garden on the 5th. The ground level includes retail space, an entrance lobby, and covered bicycle and car parking, as well as access to a shared courtyard. The courtyard is deeded back to the city, providing an attractive civic amenity to the neighborhood, and the building's office and business spaces support the area's rapidly increasing residential density.

Radiator. Portland, Oregon. Architect: PATH Architecture. Photo: Josh Partee

At five stories, The Radiator is leading a surge of mid-rise mass timber buildings in the U.S. The extensive use of wood begins with the building's structure: gravity loads are handled through a system of glulam beams and columns, and light-frame dimension lumber walls provide the structure's shear capacity. A thick timber decking creates the structural floor diaphragm, and its lightness relative to other building materials translates into a more efficient and resilient overall structural system. The Radiator is fully sprinklered, which allowed the design team to put the structural system on display; beams, columns, and the underside of the floor decking are left exposed, contributing to the interior's contemporary industrial character. Located in the Pacific Northwest, The Radiator's moisture management system is comprised of fiberglass mat gypsum sheathing, a peel and stick water/air/vapor barrier, and rain screen. This Type III, 36,000-sf project was completed in 2015 for a construction cost of $8.5 million.

ADDITIONAL RESOURCES

Think Wood
www.ThinkWood.com

Think Wood connects you to in-depth research, tools, CEU courses, case studies, code and technical experts and more, to inspire ingenuity and to demonstrate all the possibilities of wood in the built environment.

Wood Products Council, WoodWorks
www.woodworks.org

If you're working on a multi-family wood building project, technical assistance related to all of these concepts is available from WoodWorks-Wood Products Council, either by contacting your local representative (www.woodworks.org) or emailing the help desk at help@woodworks.org.

American Wood Council
www.awc.org

The American Wood Council is committed to ensuring a durable, safe, and sustainably built environment. To achieve these objectives, AWC contributes to the development of sound public policies, codes, and regulations which allow for the appropriate and responsible manufacture and use of wood products. The AWC supports the utilization of wood products by developing and disseminating consensus standards, comprehensive technical guidelines, and tools for wood design and construction, as well as providing education regarding their application.

ENDNOTES

1 *Life Cycle Environmental Performance of Renewable Building Materials in the Context of Building Construction, Consortium* for Research on Renewable Industrial Materials, Phase I 2005, Phase II 2010; *A Synthesis of Research on Wood Products and Greenhouse Gas Impacts*, Sarthre, R. and J. O'Connor, 2010, FPInnovations; Werner, F. and Richter, K. 2007, *Wooden building products in comparative LCA: A literature review*, International Journal of Life Cycle Assessment

2 See endnote 1.

3 The Wood Carbon Calculator for Buildings was developed by FPInnovations, WoodWorks and the Canadian Wood Council; available at woodworks.org

4 Case study, http://woodworks.org/wp-content/uploads/Stella-CaseStudy-WEB.pdf

5 Case study: All-wood Podiums in Midrise Construction, APA, https://www.apawood.org/publication-search?q=n110&tid=1

6 *The ShakeOut Scenario—Woodframe Buildings*, URS Corporation, prepared for the U.S. Geological Survey and California Geological Survey, 2008

7 youtube.com/watch?v=c25HuZeQsyo&context=C3f612acADOEgsToPDskLH3EQs-aodM9-NsZgF2lGi

8 U.S. CLT Handbook, http://www.thinkwood.com/products-and-systems/masstimber

RESEARCH LIBRARY

research.thinkwood.com

SEISMIC & FIRE

photo: naturallywood.com | KK Law

PERFORMANCE

photo: Skidmore, Owings & Merrill

DESIGN & SYSTEMS

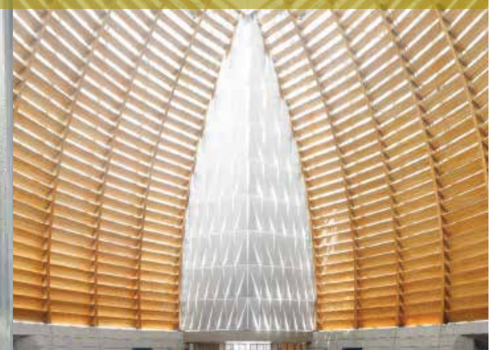


photo: Timothy Hursley & Cesar Rubio

For current mass timber research in the United States and worldwide, including CLT and tall wood buildings, the Think Wood website includes a library of studies, categorized by topic area and updated regularly.

DESIGN GUIDANCE AND RESOURCES

There are many resources available to architects and engineers designing mass timber projects.

- For general information, the Think Wood website (www.thinkwood.com) offers an expanding library of materials on mass timber products, research, building examples, and developments related to tall wood buildings.
- The National Design Specification (NDS) for Wood Construction (www.awc.org) is the IBC-referenced design standard for lumber, glulam, SCL, and CLT, including fire design, fasteners and connections, etc. A mass timber building in the United States cannot be designed without the NDS.
- The U.S. CLT Handbook (www.thinkwood.com) includes detailed technical information on the use of CLT. It should be used in conjunction with information provided by manufacturers since most CLT currently available in North America is propriety (i.e., lay-ups aren't standard across suppliers).
- APA Product Reports (www.apawood.org/product-reports) signify a product's compliance with relevant provisions of the model building codes. The L-Series covers products manufactured from lumber, veneer, or other wood base, such as glulam and structural composite lumber (SCL).

For one-on-one support (at no cost), technical experts at WoodWorks are available to provide free project assistance related to nonresidential and multifamily buildings in the United States, including those using mass timber. Designers have the option of contacting an expert in their region (www.woodworks.org/projectassistance) or emailing help@woodworks.org.

QUIZ

1. Compared to other materials, installation time for wood construction is typically:

   a. greater.
   b. slightly more.
   c. equal.
   d. less.

2. From a carbon footprint perspective, wood:

   a. stores carbon for the lifetime of the building or longer if the wood is reclaimed and reused or manufactured into other products.
   b. loses an average of 4,000 metric tons of CO_2 per five-story building.
   c. stores carbon until it is cut into lumber.
   d. loses carbon into the atmosphere once the building is enclosed.

3. Multi-story light frame wood construction generally falls under:

   a. Type I and Type III construction.
   b. Type IV and Type V construction.
   c. Type III and Type V construction.
   d. Type II and Type III construction.

4. IBC allows increases in building height and area for wood construction:

   a. only if a sprinkler system is installed.
   b. if there is a parking area but no yard in front of the building.
   c. when a mezzanine half the size of the floor below is added.
   d. if fire walls are installed.

5. The design of the joints between building envelope components, such as windows and doors, must allow for:

   a. moisture retention.
   b. differential shrinkage.
   c. continuous load paths.
   d. airflow.

6. When a multi-story wood-frame structure is built over a concrete podium, the building is treated by code as separate and distinct buildings:

   a. for purposes of height, area and continuity of fire walls.
   b. only if there are fire-resistant wall assemblies in the wood structure.
   c. if the concrete podium has two levels of parking beneath it.
   d. only if the wood structure has four stories.

7. Fire-retardant-treated (FRT) wood is an acceptable substitute for a non-combustible material for a:

   a. Type IIIA exterior two-hour rated bearing wall.
   b. Type VB exterior one-hour rated bearing wall.
   c. Type VA exterior one-hour rated bearing wall.
   d. None of the above

8. True or False: Shrinkage effects need not be considered for horizontal framing members in the wall and floor design.

9. During an earthquake wood frame structures offer a high strength-to-weight ratio, which results in:

   a. low inertia force compared with concrete or steel.
   b. higher inertia force compared with concrete or steel.
   c. containment of transfer loads induced by seismic activity.
   d. fewer redundant load paths.

10. Panelized systems:

    a. are manufactured on site.
    b. offer better quality wall construction.
    c. optimize stud design.
    d. both b. and c.

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