

Figure 1 – Typical mid-rise wood-frame building under construction.



# MID-RISE WOOD-FRAME CONSTRUCTION:

## *A Good Idea, or Are We Asking for Trouble?*

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### **ABSTRACT**

Recent changes in the building code helped fuel the current surge in mid-rise wood-frame construction projects. Over the past several years, there have been an increasing number of water intrusion claims in relatively new mid-rise wood-frame buildings. While the code requires the building envelope to provide protection from the weather, it does not provide the details necessary for designers and/or contractors to meet this requirement. Typical construction details that have had limited success on one- to three-story wood-frame buildings are even more problematic on taller buildings. Specifically, vertical and lateral movements, caused by frame compression, wood shrinkage, external loads, and material incompatibility, can compromise the function of flashing and waterproofing details. Differential movements between the wood framing and exterior cladding components can cause physical damage to building envelope components that increases the extent of water intrusion. Once water reaches the wood framing components, significant damage, such as rot, corrosion,

and mold, can result. Additionally, once compromised, the effectiveness of products used to meet fire resistance requirements is unknown. If our design and construction of the building envelope does not incorporate “best practices,” mid-rise wood-frame buildings may become the black eye of the construction industry.

### **INTRODUCTION**

We are in the middle of a construction boom. Much of the boom is being driven by mid-rise wood-frame buildings. Many of these projects are constructed as apartments located proximate to colleges with a significant student housing market. Student housing is being provided very quickly and most affordably by (what are now) code-compliant wood-frame buildings that are typically in the range of four to six stories in height (*Figure 1*).

In very short order, these structures are showing significant problems associated with building movement, water intrusion, and cladding distress and deflection, which all serve to negatively impact their durability and long-term habitability. How can our new

buildings have so many problems so early in their service lives? Unfortunately, there is not one simple answer. There are a set of product, code, ordinance, and economic issues that serve to create the “perfect storm” for construction problems to develop. This paper will outline the most significant issues facing this type of construction. Hopefully, this paper can serve as a notice to the construction industry of these issues so that we can make necessary improvements to reduce the extent of the problems.

### **LIMITATIONS OF WOOD FRAMING**

Standard wood framing is perfectly fine for a one- or two-story residential structure. However, a four- to six-story wood-frame structure is associated with numerous challenges that need to be addressed. Specifically, the issues described below should be considered for mid-rise wood-frame buildings.

#### **Frame Compression**

When wood framing is assembled, it is not perfect. Minor gaps at joints will exist throughout the structure. As the wood





Figure 2 – Typical ponding where the valley of a roof cricket is less than ¼ inch per foot.

framing receives load during construction (i.e., exterior cladding, interior drywall, flooring, etc.), the gaps will close as the frame assembly compresses. Collectively, these gaps can add up to more than 1 inch of compression over four to six stories.<sup>1</sup>

### Frame Shrinkage

Even if a building is well constructed, such that bulk water intrusion does not occur, changes in equilibrium moisture

content will cause the wood to expand and contract in service. Even minor changes can add up to be significant when they accumulate over four to six stories. Shrinkage calculations are necessary to avoid performance problems with the finished buildings. Specifically, if not considered, framing shrinkage can cause damage to plumbing fixtures and exterior cladding components and can cause water intrusion due to vertical movement. Shrinkage calculations are now required by code for wood-frame buildings greater than three stories.<sup>2</sup> Significant wood shrinkage has been seen in buildings less than three stories. There are a few things the designer can do to reduce wood shrinkage.

Wood is a hygroscopic material that

readily absorbs moisture. Therefore, it is essential that the wood framing (i.e., vertical wall framing and wall sheathing) have a relatively stable moisture content. In the southeastern United States, equilibrium moisture content of wood framing components (not subjected to water intrusion) is typically in the 12 to 15 percent range. Cyclical exposure to elevated moisture can be associated with decay, strength loss, and mold growth. These are problems that have been investigated on thousands of one- to three-story wood-frame buildings.<sup>3</sup> Making larger buildings out of wood only increases the potential for problems, particularly when typical construction practices are used.

### Creep

Wood will permanently deform when overstressed for an extended period of time. This phenomenon, known as creep, can be particularly important for the long-term performance of low-slope roofs.<sup>4</sup> The building code has long required a minimum slope of ¼ inch per foot. Even when complying with this requirement, ponding occurs along the valleys of roof crickets that have a slope less than ¼ inch per foot (Figure 2). This slope is further reduced when wood roof trusses deflect under the load of HVAC units. This can be a self-perpetuating problem. Once the slope is lost and water begins to pond, overstress and associated creep occur. At that point, the best case is that a roof leak develops and gives notice to the occupants of a problem. The worst case is a roof collapse.

### Reduced Wood Strength

Anyone involved with wood-frame construction is likely familiar with the adjustment that was made to wood strength properties (i.e., Southern Yellow Pine) several years ago. While it may not seem like a big deal, the previously published wood strength properties had been unchanged for many decades.<sup>5</sup> The wood used in construction today is grown as a crop that is typically harvested over a relatively short period of time. As building codes have changed to allow more wood to be used, there has been a corresponding marketing effort to promote wood construction. In the state of South Carolina alone, wood



Figure 3 – Mid-rise wood-frame building fire in Kansas City, Kansas.



Figure 4 – Failure of fire-resistant paint that was intended to protect a combustible OSB roof deck.

represents the state's largest cash crop, at over \$18 billion annually. To say that wood construction is a significant economic and political issue would be an understatement.

The fast-growth wood used in construction today is generally less durable and not as strong as wood used in older structures. Older, slow-growth timber generally has a clear grain and fewer defects. Because the characteristics of the wood used in construction have changed, designers need to adjust framing details to limit the movements that will occur during the service life of the building. Otherwise, these movements could result in damages to interior and/or exterior finishes attached to the framing. Movement of exterior components can result in gaps and openings that will allow water into the wall assembly. Therefore, providing adequate protection of the wood is essential.

### Fire Resistance

While we have done a good job making wood-frame buildings safer against fire—using sprinklers, fire-rated gypsum, and fire-retardant treatments—the fire resistance is generally not accomplished until the construction is complete. Unfortunately, there have been numerous fires of mid-rise buildings while under construction. A blaze destroyed the Monroe Apartments in Portland, Oregon, that were under construction in 2014. Sadly, the 2014 fire in Portland was only one in a string of fires in mid-rise, wood-framed buildings, as they've gone up in New Jersey, Texas, Washington, Wisconsin, California, Missouri, Utah, Maryland, Massachusetts, and Canada.<sup>6</sup>

While this paper was being prepared in the spring of 2017, catastrophic fires of mid-rise wood buildings occurred in Raleigh, North Carolina; Kansas City, Kansas; and College Park, Maryland. Because these buildings are often constructed as “urban infill,” the impact of a significant fire can reach far beyond the subject building (Figure 3). It is important that protective measures are put in place during construction and that the completed project provides the required level of fire resistance.

One method of providing fire resistance to wood construction is to apply an intumescent coating over combustible oriented strand board (OSB) that is used for roof decks and wall sheathing. This approach comes with its own set of problems. Specifically, the high temperatures associated with roof decks have caused the

wax (which is used in the manufacturing of OSB) to heat up and compromise the adhesion of the coating such that it falls from the surface that it is intended to protect (Figure 4).

Additionally, some coated wall sheathing panels are sensitive to moisture and are not allowed to get wet during storage and installation. This is a requirement that is nearly impossible to meet when constructing a mid-rise building. The only way to keep four to six stories of wall sheathing dry during construction is to put a tent over the

entire project. This simply does not happen, and buildings are being constructed with water-damaged sheathing with unknown fire resistance (Figure 5).

### Wood Is a Natural Product With Imperfections

It is great to use products that are natural and renewable. Wood is truly a green product. However, natural products also have disadvantages. Wood is not perfect. Wood has knots, variations in grain, and imperfections that can reduce strength and dura-



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Figure 5 – Water-damaged fire-resistant paint that was intended to protect combustible OSB wall sheathing.

bility. Engineered wood products—such as plywood, oriented strand board (OSB), and cross-laminated timber (CLT)—attempt to reconstruct the wood into more predictable and reliable forms that reduce the variability of the wood properties. However, the more

wood is refined, the more susceptible it is to moisture.

Vertical wood framing is typically accomplished by assembling various dimensional lumber products, such as 2x4s, 2x6s, etc. These framing components have numerous imperfections that cause walls to be out of square or plumb. Specifically, these framing members can twist, cup, warp, split, etc.—particularly if lower lumber grades are used. As previously stated, the wood currently used in construction is generally of lower quality when compared to wood used in older buildings, generally associated with its faster growth and consequent reduced strength.

#### ORDINANCE-DRIVEN ARCHITECTURE

Developers and contractors typically have to comply with local ordinances that are intended to protect the character of the community by setting architectural and zoning standards. However, most of these mid-rise, wood-frame buildings look very similar and serve to diminish the architectural character of the communities that have experienced this type of development. Many ordinances have created detailing challenges that, if not properly handled, will be detrimental to the performance of the building. A few examples are provided below.

#### Inside/Outside Corners

In order for these larger buildings to have architectural appeal (and not just be a plain wood box), many local ordinances require exterior walls to include setbacks or reveals

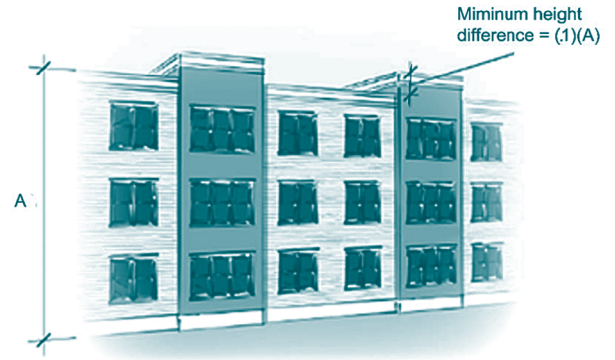


Figure 6 – Typical ordinance-driven architectural details that require walls to have “reveals” in exterior walls, creating numerous inside/outside corners.

(Figure 6). By moving the walls in and out, numerous inside and outside corners are created. These corners require attention to detail properly. Specifically, the drainage plane (typically consisting of components such as a weather-resistive barrier [WRB], self-adhered flashing [SAF], liquid-applied waterproofing, and metal flashing), needs to be constructed in a manner that provides continuity.<sup>7</sup> An open gap, joint, or unsealed and/or reverse lap can, and often does, lead to significant water-related damage.

#### Parapets

Many local ordinances require the top of the wall that extends above the roof (i.e., parapet) to be offset vertically. This requirement (similar to the walls) creates waterproofing challenges at transition points. Additionally, the general contractor needs to coordinate the work of the framer, the roofer, the sheet metal installer, and the exterior cladding installer to make sure that the work of each trade is properly integrated at these locations, particularly at areas where the work of multiple trades intersects.

#### Balconies

Balconies are a popular feature on many mid-rise buildings. They may or may not be addressed by local ordinances. However, balconies require careful detailing to prevent water intrusion; this is true no matter how tall the building is. Balconies require slope to drain. While the code has done a good job in requiring slope on roof surfaces, the code has not done a good job addressing balcony drainage.<sup>8</sup> Their surfaces can actually be more problematic than roofs. Balconies are accessible to the building occupants via a door opening (typically in close proximity to the balcony surface), and



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Figure 7 – Brick damage caused by differential building movement.

they require a structural guardrail for the safety of the occupants.

Proper detailing is critical where balconies intersect exterior walls, particularly when the balcony framing penetrates the exterior cladding and interrupts the drainage plane. Water intrusion at these intersections is not only a nuisance to the occupant, but can cause a potentially life-threatening safety issue if corrosion or decay of wood framing develops. Additionally, the guardrail details (material selection, attachment, and waterproofing) need to be carefully considered so that the guardrail integrity (or the integrity of the underlying wood substrate to which the guardrail is attached) is not compromised during the expected service life of the building, creating a life safety issue.

**Multiple Exterior Claddings**

Many ordinances require a mixture of exterior cladding types (i.e., brick veneer, stucco, cement board siding, metal panels, glass storefront) to create an attractive and interesting appearance. Some of the desired claddings can be incompatible with wood framing, particularly if used on a four- to six-story building. One example is brick veneer. Brick veneer grows. Wood framing can shrink and/or compress. Even if proper flashing details are provided to direct water away from the building at the time of construction, the differential move-

**Wood rot caused by water intrusion is the most common investigated problem.**

industry on how to deal with it.

Other desired claddings, such as stucco, are brittle. The movements associated with mid-rise wood-frame buildings can be more significant than steel-frame curtainwalls or reinforced concrete-frame buildings. This is even more important at higher floors, where the building drift is greater. This movement can result in cracking of stucco façades. The cracking is typically more pronounced at higher elevations and building corners. Don't forget that building corners are also where water intrusion and building envelope issues exist. When the wood frame gets wet, it is susceptible to decay.

Another water intrusion area in stucco-clad buildings exists where the two layers of WRB are not integrated at a penetration (i.e., window or roof/wall intersection), and water is directed between the two layers. The wall assembly is overwhelmed with water, the wood framing gets wet, and the decay process begins (Figure 8).

A building designer must know the cladding characteristics and limitations to properly design the wood framing.

**No Roof Overhang Required**

After more than 25 years of forensic investigation of building damages, it is the author's experience that wood rot caused by water intrusion is the most commonly investigated problem; nothing else even comes

the brick veneer and wood framing could serve to damage the brick or an adjacent wall component (such as a window), and/or reverse the slope of the flashing and direct water toward the building (Figure 7). This is a big problem, and will continue to be a problem if we do not educate the construction



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Figure 8 – Moisture damage behind stucco caused by improper integration of two layers of WRB.

close. Until we can get building envelopes to stop leaking and/or properly manage the water that penetrates the building envelope, water damage will remain a significant issue with wood-framed buildings. Taller wood buildings will only serve to make the problems and damage more significant.

There is a direct correlation between the extent that a roof overhang exists and water damage to exterior walls (Figure 9). This would be a meaningful architectural discussion to have on all new construction projects. The more protection we can provide, the longer the building will last!

## OTHER FACTORS

### Disconnected Occupants

Most mid-rise wood-frame buildings are being constructed to serve as apartments. These apartments typically provide temporary housing for younger occupants, such as college students. College students can be more abusive to a building than older, longer-term occupants. Therefore, less robust construction will likely show signs of distress earlier in the service life of the building, when compared to an owner-occupied single-family home or condominium of similar construction. Additionally, water intrusion is simply a nuisance to the temporary occupant that may be overlooked and/or improperly addressed, such that more significant damages can develop.

When an apartment problem is report-

ed, many times the symptom is dealt with instead of the cause. If water intrusion is observed, the damaged area may be repaired and some exterior caulk applied to prolong the reporting of the next problem. This cycle can serve to significantly increase the extent of damages, sometimes to the point that structural integrity can be compromised and the interior building conditions (i.e., mold growth and air quality) can be a health risk to the occupant. This is not to suggest that owner-occupied mid-rise condominium buildings are not problemat-

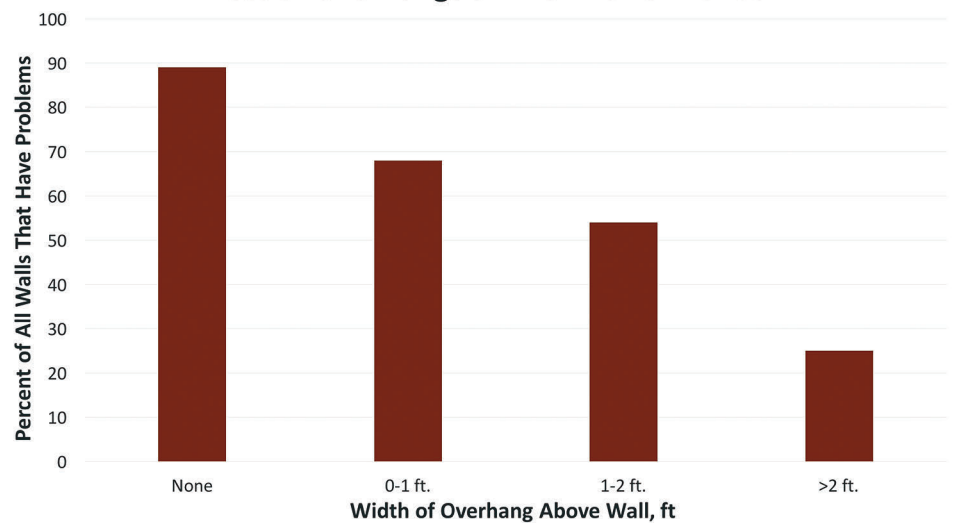
ic; however, when the occupant has “skin in the game,” an appropriate and comprehensive response to a problem is more likely.

### Municipalities Don’t Know Any Better

Most municipalities (city and county governments) serve as the Authorities Having Jurisdiction (AHJ) that enforce building codes. Most AHJs have a misconception that any development is good development, or that if you are not growing, you are dying. That is simply not true. No development is better than marginal (code-compliant but less-than-durable) development. The misconception is that the benefits of development—such as tax revenue, stimulation of the local economy, and affordable housing—will outweigh the negative consequences of development. However, there are negative consequences associated with fast-paced development of marginal construction projects. Specifically, the lack of durability will cause distress to these buildings that will require repair early in the life of the structure. In the meantime, water intrusion damages can compromise the safety and/or welfare of the occupants.

To make it worse, the marketing of wood construction (since 2009, code revisions have allowed larger buildings of wood construction) has been significant. Elected officials are not typically construction experts, and are not expected to be. If they are meeting the building code, there is generally no interest in requiring anything better. In fact, there seems to be concern that development would slow down if construction standards were to become more stringent. However, we

### Effect of Overhangs on Wall Performance



Source: Survey of Bldg Envelope Failure in the Coastal Climate of BC; Canada Mortgage and Housing Corporation, [www.cmhc-schl.gc.ca](http://www.cmhc-schl.gc.ca)

Figure 9 – Correlation between lack of roof overhang and water damage.



Figure 10 – Water intrusion/damage of a mid-rise wood-frame building under construction.

should be happy to swap marginal and fast for better and slower any day of the week.

#### Misguided Construction/Design Budgets

Too often, emphasis is placed on the amenities of a development and not on what matters most. Specifically, instead of spending more money on properly detailing the structure, the roof, the windows, the doors, the waterproofing, the exterior cladding systems, etc., money is spent on frivolous extra features that will attract tenants to rent. Some of the features that serve to reduce the budget for things that actually matter include, but are certainly not limited to, the following:

1. Swimming pool(s)
2. Lazy rivers
3. Pool decks with DJ booths
4. Social rooms with pool tables, bars, big-screen TVs, etc.
5. Fitness centers
6. Volleyball courts
7. BBQ areas

While these features serve to attract tenants, they should only be built in addition to a well-constructed building—not in lieu of.

#### Misguided Construction Schedules

Since many of these buildings provide student housing, an accelerated and sometimes unrealistic construction schedule may be pushed onto the construction team. Most often, regardless of when construction com-

mences, there is a desire for occupancy in August of a given year, corresponding with the beginning of the fall semester for most universities. The attempt to condense the schedule can create inappropriate sequencing of trades that allows water intrusion to begin before construction is even near completion (Figure 10).

Specifically, instead of an orderly sequence of framing, WRB installation, window installation, and cladding installation, contractors will have a haphazard combination of multiple trades on the building—all at the same time, creating easy opportunities for water to be trapped in the exterior wall assembly (Figure 11). In some cases, significant water intrusion repairs are needed before the construction is even completed.

The resulting water damages during construction can cause major delays and cost overruns. There needs to be much more focus on proper construction than meeting unreasonable deadlines. This has always been a challenge in the construction industry. However, these buildings (and their occupancy type) make the challenge bigger than ever.

#### ENGINEERING/WOOD SCIENCE/ BUILDING ENVELOPE DISCUSSION

Engineers and wood scientists have done a great job of developing a wide variety of engineered wood products. However, no matter how great the engineering and/or wood science is, it is still wood. Wood-based products will always have limitations in



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Figure 11 – A haphazard sequencing of multiple trades on the exterior wall of a building under construction.

constructed assemblies that are exposed to the weather. The most significant limitation is that wood performance (i.e., dimensional stability, strength properties, fastener withdrawal resistance, etc.) diminishes when exposed to elevated moisture conditions. Additionally, the presence of elevated moisture at wood connections (typically carbon steel fasteners, such as nails, screws, or bolts) has the potential to compromise the integrity of the structure. Corrosion of fasteners is routinely found to be a contributing factor of residential wood deck collapses.

A durable building envelope must be able to receive, manage, and shed water. The construction materials that the water touches along its path after landing on a building must be durable and not sensitive to moisture. The entire path that the water follows must be protected and free from “alternate paths” created by gaps, openings, reverse laps, etc. that could allow water to penetrate to deeper, unprotected locations where hidden damage can develop. In general, the shorter the path, the better. The less dwell time the water has on building surfaces, the better the wall will perform. The basic exterior wall design concepts for improved durability are often referred to as the four Ds (Figure 12):


- 1) Deflection
- 2) Drainage
- 3) Drying
- 4) Durability<sup>8,9</sup>

#### SUMMARY/COMMENTARY

As a professional engineer, I love wood. I have done most of my design work with wood. Unfortunately, most of my forensic investigations have been associated with damaged wood-frame structures. While I would have the most to gain (from a forensic engineering business standpoint) by saying nothing, I find it sad that the construction industry refuses to learn from past mistakes and is content to stay on the faster and cheaper construction path. I am content

to continue investigating damaged wood buildings. However, I have a strong desire to improve the construction industry, and feel that a warning article is necessary, particularly given the pace and attention (i.e., marketing) that wood construction is currently getting.

I strongly recommend that we slow down and figure out how to build structures that will last, and spend less time on how to build them more cheaply and more quickly. Until then, I (along with other experts and construction litigation attorneys) will enjoy the abundance of work provided by investigating damages associated with typical construction practices. It seems that if we wanted to “make America great again” (no political endorsement intended), we could start by building better stuff.

In summary, mid-rise wood-framed buildings may be allowed by the code; however, if we don’t start changing our construction practices to deal with the challenges, we are asking for trouble. 

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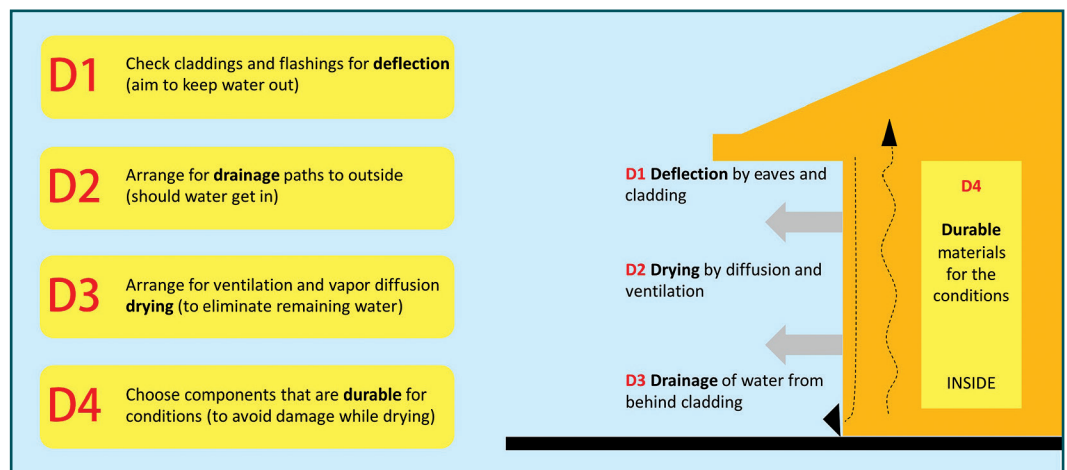


Figure 12 – The Four Ds of Wall Design.