Frameworks for Success

Why window and door frame materials matter

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OVERVIEW

Most architects know that the successful integration of windows and doors into their designs is often critical to their success. There are dozens of decisions the architect needs to make to include a window or door in the design of a building, and perhaps none is more important than the selection of the frame material.

WOOD AND CLAD WOOD

Wood is certainly the most prevalent window and door frame material, which has been in use for over 1,500 years. But simply describing it as “wood” is no longer adequate given the range of products that now fall under this description. Historically, the frame would be made of a single piece of wood that would be shaped in the shop or factory to serve its role as sill, side jamb, or head jamb and joined at the corners with metal fasteners. Species that were employed could originally be specified by the designer, but have evolved to be selected by the manufacturer, and the designer selects from what is available.

The more prevalent species of wood used for window and door frames in the United States seem to be pine, mahogany, Douglas fir, and white oak. Certainly, the warmth of a natural wood finish on the interior is a major design feature. When properly protected, the exterior wood can last much longer than the typical expected useful life of a window.

The architect should carefully review the specifications and needed product performance to ensure the structural capabilities of a wood window. Some wood frames are comprised of multiple pieces that are finger-jointed and/or laminated together, which can have different structural characteristics than single-piece frames. Finger-jointed and laminated wood frames can be strong and are more dimensionally stable than solid single-piece wood frames but can be limited in bending strength unless specifically engineered to achieve longer spans.

ALUMINUM CLADDING

Aluminum cladding of windows and doors gained popularity in the 1960s and has evolved since that time. Wood frames can be clad with aluminum, which is generally achieved with either roll-formed aluminum cladding that was quite thin or the more effective approach, which involves an outer layer of extruded aluminum. The extruded aluminum portion of the frame can provide a number of sectional profiles to enhance traditional

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to contemporary designs and has sharp edges, which provide crisp shadow lines and tight joints. This ability to customize the profile for a specific project provides the architect with design flexibility. With contemporary coating technologies, the range of color choices is endless, and the durability is exceptional (30-50 years). With a separate extruded aluminum shell that is structurally bonded to a wood frame, they act as a composite assembly that results in greater strength, enhanced resistance to moisture damage and rot, as well as improved thermal performance than either could achieve alone.

CROSS-SECTION OF EXTRUDED ALUMINUM-CLAD WOOD WINDOW SASH.

ACETYLATED WOOD (ACCOYA®)

Care should be taken when referring to “wood” as a material, as the term now encompasses a wide range of products, including solid timber, modified wood, and composite materials. Acetylated wood, which is commercially available under the trade name of Accoya®, is a modified solid wood product, typically manufactured from fast-growing species such as radiata pine. The modification process involves reacting the wood with acetic anhydride, which alters the chemical structure of the cell wall polymers. This reaction reduces the number of hydroxyl groups within the cell wall, thereby limiting the wood’s ability to absorb moisture. As a result, the material exhibits significantly improved dimensional stability and increased resistance to biological degradation. No toxic residues remain in the wood following modification, and process by-products are recovered and reused within the system. Compared to unmodified timber, acetylated wood demonstrates a significant reduction in swelling and shrinkage, improved coating performance, and extended service life in exterior applications such as window and door components. While the initial material cost may be higher than conventional timber, the extended service life and reduced maintenance requirements can result in a lower overall lifecycle cost.

THERMOPLASTIC COMPOSITE:

This category of materials will become “plastic” or moldable when heat is present. This contrasts with thermoset composites, which become permanently set after the application of heat. The differences between these two categories of composites are significant, so much so that they now have distinct CSI specification sections.

Thermoplastic composites are more economical to produce, have a lower first cost, and are easier to recycle. Thermoplastic composites can contain vinyl and wood fibers and are heated or melted and poured into forms. It also has a high strength-to-weight ratio, is naturally water resistant, has a low resistance to impact, and a higher expansion/contraction rate when compared to thermoset composites.

Vinyl

This is the most common thermoplastic composite, and its primary advantage is a low initial cost. It is often used as a cladding material or for a portion of a composite frame assembly over a wood sub-structure. As the only material in a window frame, it is less rigid and more prone to thermal movement than many of the alternatives. Most lower-quality vinyl windows will off-gas, causing them to turn yellow and become brittle after exposure to sun and heat.

Vinyl is a natural insulator and resists any damage due to exposure to water. It is, however, typically limited in color selections, and due to its low flexural strength, it may be inappropriate for larger openings. Vinyl frames can be reinforced with steel inserts to increase strength, but these inserts can be deleterious to thermal performance.

CORNER SAMPLE OF VINYL WINDOW.

THERMOSET COMPOSITES

This category of materials is created through a chemical process that permanently changes the material at a molecular level. As a result, thermoset composites do not melt or soften when exposed to high temperatures. Due to their permanent nature, they also outlast thermoplastic composites, which results in a lower life cycle cost. Examples of thermoset composite materials used in window and door frames are discussed below.

Fiberglass

Glass fibers are encased in resin to make what is commonly known as fiberglass, as it relates to window and door construction. Once it is shaped, it is cured and, like concrete, gains strength through a chemical reaction that makes the shape permanent. It is water-resistant and can have integral or applied color and texture. It is typically fabricated into simple rectilinear shapes, as more elaborate profiles can be very expensive to create. Fiberglass can be reinforced by encasing steel to improve bending strength and to limit deflection, and has allow coefficient of expansion and contraction, quite similar to glass. With updated manufacturing techniques, fiberglass significantly outperforms vinyl and other thermoplastic composites in a range of categories. There are several variants, some of which are proprietary to specific manufacturers, that are utilized for window and door frames.

Ultrex®

This is the proprietary name for pultruded fiberglass from Marvin. Pultruded fiberglass is a game changer in the world of fiberglass production. Like some composite wood products, the process aligns fibers to increase strength. The process pulls continuous glass fibers known as fiberglass rovings through a die so that they are aligned and cut to suit the profile that is being created. They are then coated with finish layers that are smooth and meet or exceed all industry standards. With a relatively low rate of expansion and contraction and high strength, it is suitable for larger openings.

High-Density Fiberglass

This frame material is an enhanced pultruded fiberglass that represents a significant improvement over first-generation fiberglass. Its defining characteristic is the higher density of fibers, which are typically compressed and bonded with high-strength resin. The result is a stronger section and improved thermal and acoustic properties.

ALUMINUM

Window and door frames comprised entirely of aluminum are available for the custom residential and light commercial market sectors, and have some unique advantages. Similar to extruded aluminum clad wood windows, the exterior profile can take many shapes and be complemented by separate shaped panning pieces that tie the window frame to the surrounding wall. This ability to mimic historic window profiles and moldings with a more durable exterior makes them a good option for adaptive reuse and renovation of older buildings.

As a natural conductor, aluminum frames need to incorporate an effective thermal break to be energy efficient. With contemporary coating technologies, color and textures can be factory-applied that last 30+ years. The interior appearance of solid aluminum windows tends to blend best with contemporary or commercial interiors. Although aluminum is strong, it may also need additional reinforcement for long horizontal or vertical spans at intermediate mullions. Aluminum that is exposed to salt water and coastal environments can show pitting and corrosion without proper coatings or protection.

ULTREX FIBERGLASS EXTERIOR WITH WOOD INTERIOR.

INTERIOR VIEW OF HIGH-DENSITY FIBERGLASS CORNER SECTION.

STEEL

Window and door frames have been made of steel since the mid-1800's. It was very popular in the early 1900's and then faded in use due to materials shortages after World War II, when alternative materials like aluminum became available. Due to its high cost, its use is primarily for the high-end custom home market and light commercial projects. Steel windows can cost two to four times as much as a similar-sized extruded aluminum wood-clad window. The primary benefit of steel is that, due to its strength, the frames can be quite narrow, resulting in elegant and sleek sightlines. Steel window frames are hot-rolled sections that allow for fixed glazing and operable sash of all types. It excels at larger openings due to its overall strength and stiffness. With the introduction of thermal breaks in the frame, which makes the frame larger, some of the benefits of the narrow steel frame are sacrificed. The thermal breaks are, however, essential for adequate and code-compliant thermal performance.

THERMALLY BROKEN STEEL WINDOW.
Photo courtesy of Hope's Windows

DESIGN CONSIDERATIONS

In the hierarchy of decision-making that the architect navigates when selecting windows, it is first necessary to clearly establish aesthetic goals. It is also, however, important to know how the windows operate, as this can also impact the selection of the frame material. Some considerations for each type of operable window include:

Hinged or Casement: Operable sash is typically attached to frames with pivot hinge hardware at the sill and head jamb. The size of the sash can be quite large and will add stress or point loads to the frame at the attachment points. The dimensional stability and expansion characteristics of the frame need to be stable to ensure that the sash is sealed tightly to the frame when closed. These requirements would tend to favor the more robust frame materials, including wood, extruded aluminum clad wood, pultruded fiberglass, and thermally broken steel.

Horizontal Sliding and Double Hung: The operation of these types of windows and doors requires a certain amount of space between the sash and frame to allow it to slide. So again, the frame materials that are more robust are ideal. The materials with a higher rate of thermal movement can also be utilized, but this will necessitate an even larger gap to ensure that the sash slides easily in all temperature conditions. This will increase air infiltration and reduce their energy efficiency.

Hopper and Awning: Hinges for these window types are at the head and side jamb, and similar to the casements, need to be properly designed to handle the point loads of the hinges. These window types generally have smaller operable sashes, but the issues are still the same as casement windows, so the more robust frame types are preferred.

Sightlines

Architects are typically concerned with sightlines as they can have a big impact on overall appearance. While frame depth can also impact sightlines, it is primarily the dimension on the exterior and interior face that is most concerning. The specific context of the window in the overall design will govern how much the frame width is perceived. A single large fixed window can have a high percentage of glass area to opening area, even with a relatively large frame, while an operable double hung window in a small opening will have a low percentage, even with a narrow frame. So, sightlines need to be considered based on the overall aesthetic goals of the project and the opening and operation type that is selected.

Exterior Considerations

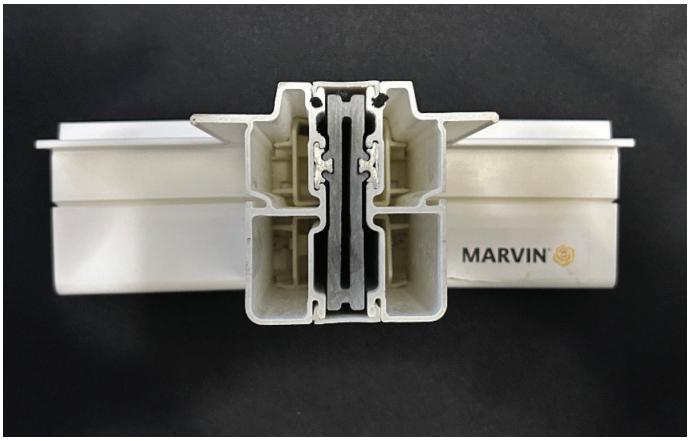
Window and door frame materials are a critical part of the exterior appearance and the longevity and durability of the whole building. While the expected useful life of a window or door is in the range of 15–50 years, they are more or less a permanent feature of the overall exterior design. The factory-applied frame coating options now available for the exterior of the frame material are virtually endless, offering a wide range of colors that will not degrade or fade and are scratch-resistant. Architects should reference AAMA 2605 and 625 for standards for exterior finishes based on the material substrate. While most manufacturers offer a limited palette of colors in their product lines, there are several that offer custom colors and or textures for an additional cost. Generally, color retention is best on metals—steel and aluminum, followed by fiberglass, wood, and vinyl.

Interior Considerations

Similarly, window and door materials can have a big impact on the look of the interior. Most window and door jambs do not span the full depth of the wall section without added extension jambs. Some materials, like vinyl, fiberglass, and steel, are not typically available with extension jambs of the same material. Wood and extruded aluminum-clad wood windows can typically be provided with either loose or attached wooden extension jambs.

SPECIAL OR UNIQUE INSTALLATIONS

The most prevalent features that require special consideration are multiple windows or doors installed in a single opening. This will involve intermediate vertical or horizontal mullions, which can simply be standard double-wide jambs of unitary window and door frames or require a structural element between window or door units. For modest sizes, factory-mulled units can also have supplemental structural elements installed at the factory. Larger "structural mullions" will need to be designed by the architect, as it is an independent element which is not typically the responsibility of the window or door provider.



STEEL-REINFORCED VERTICAL MULLION.

GREEN BUILDING AND WINDOW AND DOOR FRAME MATERIAL

The long-term sustainability of a window or door frame material should factor into the selection process, and it has a number of key considerations, including:

– Life cycle cost of the material

– Carbon footprint and embodied energy of the material

– Energy Efficiency of the material

Life cycle cost analysis, or LCCA, involves the initial cost and the expected useful life of the material or product. Consumers are typically focused on the first or initial cost of products and services, so this is most often used in evaluations of affordability. If a high-quality extruded aluminum-clad wood-framed window initially costs 20% more than a vinyl-framed window but lasts twice as long, it has a much lower life cycle cost. This has both a long-term cost benefit and an environmental one in that it uses less material. The long view is often challenging to adopt when durations for the life of better windows are in the 25–50 year range, buildings are owned for on average 12–13 years, and typically financed for 30-year term mortgages that are refinanced every 7-8 years.

There has been much discussion lately on the carbon impact of the creation of materials and products. This can also be viewed as the initial impact of the window or door prior to purchase, sometimes referred to as the "cradle to gate (of the factory)" phase of the life cycle. Again, the full life of the product or system should also be considered here, which includes the in-service period or "cradle to grave" and the post-service time, which is referred to as "cradle to cradle." This last view takes into account the ability of the material to be effectively recycled or renewed. There are many factors to review when analyzing how much carbon is used in the "cradle to gate" portion of the life cycle, including the cost of energy (electricity and fuel consumption) for production and delivery. There are also many innovations underway by manufacturers to reduce the carbon footprint of materials. For example, some aluminum manufacturers have recently cut their carbon use in half due to changes in production. Generally, however, cradle to gate carbon use from highest to lowest is:

– Aluminum

– Steel

– Vinyl

– Composites

– Fiberglass

– Wood

– Acetylated Wood

ENERGY EFFICIENCY

Windows are generally evaluated by their insulation value, air leakage, and solar heat gain coefficient. Frame material and design can affect both the insulation value and air leakage ratings. While it may seem counterintuitive, the opaque window and door frame material generally has a higher U value (conductivity) than the transparent insulated glass assemblies. As a result, the

thermal properties of the frame have an outsized impact on the overall energy efficiency of the window or door. U-value ratings for windows and doors are determined by an area-weighted formula, so both the size of the frame and glass and their respective insulating qualities factor into the overall U value of the assembly. Thermal breaks also impact the energy efficiency of windows and doors, which is why fully effective thermal breaks on aluminum and steel windows are absolutely essential.

Air leakage is also a consideration, and frame materials have varying abilities to maintain a tight connection to the sash. The more dimensionally stable frame materials are well-suited to reduce air leakage. Some of the materials that are more impacted by extreme temperatures, like vinyl and thermoplastic composites, are more prone to significant expansion and contraction, which could result in air leakage.

CONCLUSION

The selection of window and door frame materials is pivotal to the quality of the window or door and ultimately the aesthetics and performance of the entire building. While glass area and sightlines are often a major consideration, they cannot be achieved without the thoughtful and careful selection of the right frame materials. This critical decision process will lead or follow other major design decisions, including exterior cladding, interior trim, color selection, and wall finishes.

While some of the choices for frame materials have been proven over a long period of time, like wood, steel, and aluminum, others are relatively new and innovative. As changes inevitably continue to affect the construction industry, it is important to have a wide range of options, both tried-and-true materials and new, effective, and sustainable alternatives. Pultruded fiberglass, high-density fiberglass, and acetylated wood have posted excellent performance metrics in many categories, and there is no doubt that their use will continue to grow. Selection of the right window and door frame material is not only a necessary technical decision but also a major determinant in the success and longevity of the entire design approach.

Russell A Davidson, FAIA, served as a volunteer leader of the architecture profession in numerous roles in the American Institute of Architects, including AIA New York State President and AIA National President. He is a former president and principal of KG+D Architects, an award-winning firm in New York's Hudson Valley.