Light-frame Building Construction with 2 by 4 Lumber – The "New" Old Building System of American Housing

Leichtrahmenkonstruktionen mit 2x4s – das «neue und alte» Hausbausystem in Amerika

L'ossature bois légère en 2x4" – Le système de construction de référence aux USA, à la fois moderne et ancien

Joseph R. Loferski, PhD, Professor
Department of Sustainable Biomaterials
Virginia Tech, Blacksburg
USA-Virginia

Light-frame Building Construction with 2 by 4 Lumber – The "New" Old Building System of American Housing

Abstract

Light-frame building construction using 2 by 4s and other dimension lumber has been the mainstay of the U.S. home building industry for nearly 150 years and is as relevant today as is was in the past. While 2 by 4 construction looks "primitive" it actually is an effective and efficient way to build houses and the system performs quite well in the face of natural events like hurricanes or earth quakes. This paper examines the modern methods of building houses using 2 by 4s and other wood products, presents the basic concepts of engineered housing systems, and shows mistakes that can be made during construction.

1. Introduction

The light frame building system using small wood elements such as 2 by 4 in. lumber is a surprisingly successful and robust method for building construction, especially houses. This paper discusses some of the facts and features of the system that has been used in the USA for more than 150 years.
The statistics of building construction show that 1 and 2 million new homes are constructed each year in the U. S. and 95% of these homes are constructed using light frame construction. In 2015 nearly 1.2 million new houses are being built of which 800 thousand are new single-family homes, and nearly 450 thousand are for multiple family buildings. These large numbers show the popularity of the method.
The objectives of this paper are to introduce light frame construction, to discuss modern methods of building houses in USA and to show some construction mistakes and how to avoid them.

2. Background

Light frame building construction methods began in the 1830's in Chicago. Some authors attribute the innovation to a man name George Snow while others believe that the method evolved over time and Snow was one of many innovators. A key characteristic of light frame buildings is the use of many relatively small elements (beams, wall studs, joists etc.) that are closely spaced and covered with sheathing that distributes the load among the many elements. The advantages of the system include light weight materials, standardized elements and sizes, and fast and easy erection of the building-- all features that which contribute to low cost. The method produces strong and extremely efficient buildings in terms of material utilization.
Several key historic innovations enabled the light frame building system to become the preferred method for building houses. In the 19th century the development of water powered or steam powered saw mills simplified the production of low cost lumber compared to hand hewn beams that were commonly used in heavy timber frame buildings. Also, during the early to mid 19th century advances in technology for machine-made nails significantly lowered the cost of nails compared to those made by hand. The many hundreds of wood joists, studs and roof rafters in light frame buildings are held together by nails and without low cost nails the system would be uneconomical.

3. Standard Lumber: Nominal vs. Actual Dimensions

What is a "2 by 4"? These numbers represent the *nominal* dimension, in English units, of the cross-section of lumber that is used to construct walls in light frame buildings. These are often called "studs". Surprisingly, the dimensions of a 2 by 4 are not actually 2 inches by 4 inches! The American Lumber Standards Committee, in the 1960's, created the

standard nominal and actual dimensions for structural lumber that are used for all wood species throughout the United States. To determine the minimum *actual* cross-section dimensions for lumber the rule is: 1) if the *nominal* size is less than or equal to 6 in., then subtract ½ in. from the nominal dimension; 2) if the *nominal* dimension is greater than 6 inches subtract ¾ inch from the nominal size. For example, the actual size of a nominal 2 by 4 is actually 1.5 by 3.5 inches. Similarly, the *actual* size of a *nominal* 2 by 10 is actually 1.5 by 9.25 inches. Because wood shrinks and swells with changes in moisture content (MC), the standard sizes are for lumber at 19% moisture content, which is the typical MC for dried structural lumber. Figure 1 shows a cross-section of lumber and the nominal and actual sizes.

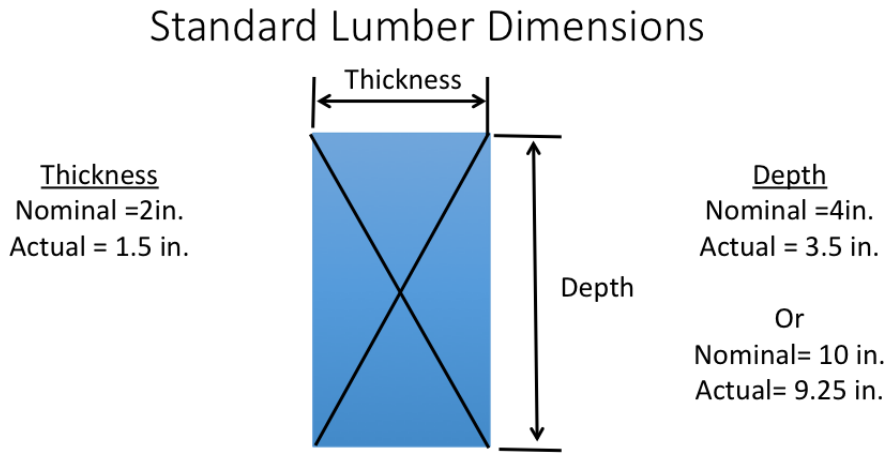

Figure 1: Standard lumber cross section dimensions in inches.

The nominal cross-section dimensions are usually based on even increments of 2 inches, although other sizes may be specially ordered. For example, the commonly used sizes are 2 by 4, 2 by 6, 2 by 8, 2 by 10, and 2 by 12 inches. The length of lumber is based in even increments of 2 feet. For example, 8 ft., 10 ft. 12 ft. are even increments of 2 feet. These dimensions have implications for designing and building houses based on even increments of 2 ft. For example, the same size and number of joists are needed for a 16 ft. wide room as for a 15 ft. wide room. Furthermore, the panel products, insulation, etc. are also based on even increments of 2 feet. Therefore maximum efficiency of material utilization can be achieved by recognizing the standard sizes.
One can observe that the size of lumber is based in the English system of measurements. Converting the dimensions to the metric system could be done but would produce awkward increments of millimeters instead of the simplicity of even numbers of the nominal dimensions for lumber.

3.1. Balloon frame vs. Platform Frame:

The original method of light frame construction was called "*balloon frame*" because of its lightweight compared to the traditionally used heavy timber frame. It is characterized by having wall studs that are continuous from the sill plate (board on the foundation) to the top plate (board at the top of the wall). For a two story building the wall studs would be very long. For example, the length of a 2 by 4 wall stud for a 2-story house would be 18 to 20 feet (approximately 5.5 to 6 meters) long! The floor joists were nailed to the wide face of the wall studs and often rested on braces that are "let into" the studs. Because of the difficulty of handling such long wall studs balloon frame construction is rarely used today. Figure 2 shows a balloon frame house wall.

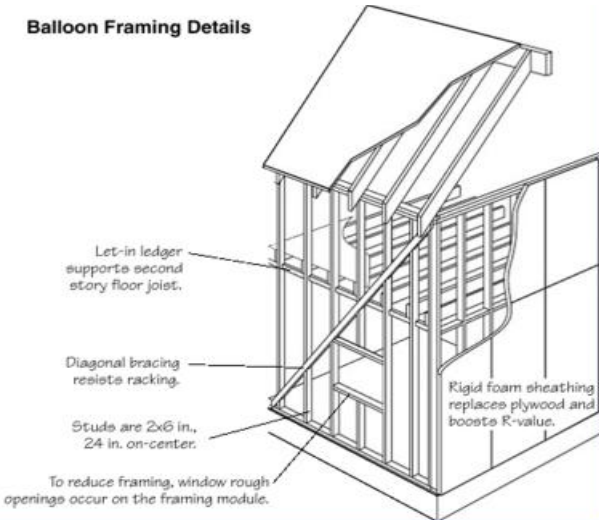

Figure 2: Balloon frame house showing continuous wall studs from foundation to top plate on wall. Floor joists rest on "let-in" braces cut into studs.

The "*Platformframe*" replaced balloon frame construction and is commonly used today. In platform frame construction the first floor is built on the foundation. It uses joists, typically 2 by 10 to 12 inches wide, sheathed with plywood or oriented strand board (OSB). The wall is built on top of the floor platform. Then the second floor platform is built on top of the walls, followed by the second floor walls. The third floor follows. Finally the roof if built on the top plate of the wall. This simple method can be used for 1, 2, 3 and 4 story houses. The building code dictates the size of the buildings and is especially regulated by fire concerns. The wall studs are typically 2 by 4's but 2 by 6's are being used more frequently to allow for more thermal insulation in the walls. The wall studs are sheathed with plywood or OSB while diagonally laid boards were used originally. The interior walls are sheathed with gypsum wallboard to provided for fire resistance, to encapsulate the insulation, and to provide for a smooth surface for easy interior decoration. Figure 3 shows a schematic of a platform frame building.

Figure 3: Platform frame building showing the second and third floors built on top of the wall studs. Sheathing of plywood or OSB is will be installed on the floors, outside walls and roof.

4. Materials

4.1. Wood Materials

A wide variety of wood materials are used in house construction. Solid wood lumber is commonly used for joists, wall studs, and roof rafters. Panel products such as plywood and OSB are used for sheathing floors, walls, and roofs. The sheathing is important for resisting lateral loads caused by wind and seismic events. Composite wood materials such as wood I-joists, laminated veneer lumber (LVL), and parallel strand lumber are often used. The advantages of these materials are high strength, consistent moisture content, and excellent mechanical properties. Metal plate connected wood trusses are often used for roofs and floors (Photograph 2). The wood truss industry has developed extremely efficient and effective designs that are commonly used in house construction especially for multiple family buildings.

Figure 4: Metal plate connected wood floor trusses being installed.

4.2. Fasteners

Many thousands of fasteners are used to build a house. Nails, screws, bolts, metal joist hangers, and other fasteners are needed. Each sheet of plywood or OSB requires approximately 33 nails to fasten it to the wood framing. Nails are hand hammered or installed by a nail gun. Elastomeric adhesives, in addition to nails, are often used to firmly attach plywood or OSB in floors joists to help eliminate the possibility of future squeaks. Proprietary metal hangers and clips are commonly used to attach joists to framing and roof rafters and trusses to the top plate using "hurricane clips" and other specialty metal fasteners. The vast number and type of fasteners is apparent when one examines a catalog of a fastener manufacturer. These connectors are usually load rated and must have building approval. The use of these connectors greatly improves the strength of a building and they have proven success in extreme events such as hurricanes and earth quakes.

5. Construction Errors:

Because of the complexity of building construction, even with a system as simple as the light frame method, errors can still happen. The many thousands of elements that must be cut to proper size, correctly installed, using the correct fasteners can lead to errors.

Also product manufactures specify correct placement and use of their products and workers may not understand these issues and miss-use the products leading to errors that may affect structural safety.
Building officials who represent each community inspect buildings during construction to verify conformance to the applicable building code. The building official has police power to enforce the rules and regulations related to all buildings in the jurisdiction. In some cases, the plumbers, electricians, or other trades may damage the wood structural elements while they are installing their products. So the carpenters are not the only trade that can cause problems in construction. Hopefully most errors are discovered during the construction when it is relatively easy to fix the problem.
Some errors that have been observed include cut truss elements (no truss element should be cut, drilled or modified except with explicit approval by the manufacturer), improperly cut I-joists (manufacturers publish requirements for drilling and cutting their products), holes and notches in lumber, improperly installed joist hangers, etc. Photograph 3 and 4 show some construction errors.

Figure 5: Improperly cut, notched and drilled floor joists by plumber.

Figure 6: Improper truss support.

6. Summary and Conclusions

The development of modern light frame construction has revolutionized building construction and is used extensively in the U.S.A. Light frame buildings are economical, efficient, strong and durable. They use many relatively small closely spaced structural elements of wood and wood products. The buildings are held together by a vast array of metal fasteners such as nails, screws, hangers and bolts. Errors in construction can occur and are often discovered by examining the building at various phases of construction. Light frame building construction is expected to be the principle method for building houses, and increasingly, for light commercial buildings in the future.