

Industrial Revolution

Every home that is built is a representation of compromises made between different and often competing goals: comfort, convenience, durability, energy consumption, maintenance, construction costs, appearance, strength, community acceptance, and resale value. Consumers and developers tend to make tradeoffs among these goals with incomplete information which increases risks and slows the process of innovation in the housing industry. The slowing of innovation, in turn, negatively affects productivity, quality, performance, and value. This department piece features a few promising improvements to the U.S. housing stock, illustrating how advancements in housing technologies can play a vital role in transforming the industry in important ways.

Reviving Rammed Earth as a Sustainable Construction Technique

Hota Gangarao

David Johnson

Ray Liang

West Virginia University

Mike Blanford

U.S. Department of Housing and Urban Development

The views expressed in this article are those of the authors and do not represent the official positions or policies of the Office of Policy Development and Research, the U.S. Department of Housing and Urban Development, or the U.S. Government.

Abstract

The status quo for single-family home construction has been wood frame construction, commonly called “stick framing” because of the dominant use of 2” x 4” dimensional lumber. Wood frame construction has served the homebuilding community well; however, alternative building approaches are beginning to catch on. The alternative discussed in this article—rammed earth—is actually a historical construction technique that practitioners are reviving.

Introduction

Rammed earth is a construction technique in which subsoil¹ is compressed within a vertical formwork to form the walls (generally, exterior) of a building. The subsoil is added layer by layer, rather than all at once. These layers are called “lifts” (see exhibit 1). Compacting each lift ensures even compression across the entire wall section. In modern use, rammed earth is typically stabilized with a stabilizing agent—Portland cement being the most common. This technique is called stabilized rammed earth.

Exhibit 1

Corner of wall with lifts clearly shown.



Source: West Virginia University

¹ Subsoil is the layer of soil under the topsoil. Subsoil is typically composed of a mixture of sand, silt, and clay.

Over the past quarter century, rammed earth construction has received renewed attention due to its desirable, green characteristics. The North American Rammed Earth Building Association (NAREBA) and other green advocates have led the movement for increased attention. This interest led to a standardization effort for the use of rammed earth and other earthen wall construction techniques the civil engineering community uses. In 2010, the American Society for Testing and Materials International (ASTM) created the *Standard Guide for Design of Earthen Wall Building Systems*, which “provides guidance for earthen building systems, also called earthen construction, and addresses both technical requirements and considerations for sustainable development.”

History of Rammed Earth

The basic construction techniques involved in rammed earth construction have been used for centuries. In China, rammed earth structures built 500–1,000 years ago remain standing and in use today (Liang et al., 2013). Several hundred years ago, the indigenous inhabitants of the southwest region of the United States were adept at using local materials (primarily earth/clay mixtures) to build durable structures that provided relative comfort against both the heat of summer and bitter cold of winter (Hardin, Merry, and Fritz, 2003).

The U.S. Department of Agriculture published one of the earliest modern technical documents for rammed earth construction in May 1937. The report noted that “no permanent building material is cheaper, and when spare-time farm labor is employed, very little cash outlay is required to erect durable structures” (Betts and Miller, 1937).

No single event started the modern era of rammed earth construction. Some practitioners never stopped employing it because of the low cost and low technology of the technique. The 2003 report by Maniatidis and Walker gives an excellent overview of the literature on rammed earth (Maniatidis and Walker, 2003).

Benefits

Rammed earth is a sustainable and natural construction material providing many environmental benefits. Possible benefits of rammed earth over wood framing include:

- Durability of the technique, which is demonstrated by historical buildings that were constructed using the same technique and are still standing to this day.
- The construction skills required to build a rammed earth wall can be easily acquired without formal training, which is especially beneficial in rural areas with unskilled labor availability.
- High thermal mass coupled with modern insulation materials of the rammed earth walls allows for the modulation of indoor temperatures. This feature makes the home more comfortable during the spring and fall.
- Low material and transportation costs due to the nearly universal availability of suitable subsoil.

Drawbacks

- One major limitation of rammed earth construction is its labor intensiveness.
- Another limitation, related to the high thermal mass of the rammed earth walls, is the slow temperature adjustment of the living space. This characteristic may happen in the winter or summer if the home's heating or cooling equipment is turned off or reduced and then turned back on. Indoor comfort can also be impacted if the heating or cooling capacity of the equipment is not able to quickly overcome the thermal mass of the wall system.

A Rammed Earth Home in Alaska

In 2016, HUD supported the construction of a stabilized rammed earth home by the Aleutian Housing Authority (AHA) in Butte, Alaska (see exhibit 2). AHA was interested in demonstrating a stabilized rammed earth (SRE) affordable home because of their desire to produce the most energy-efficient and healthiest homes possible at the lowest possible cost.

Exhibit 2

Roof assembly being constructed on the Aleutian Housing Authority stabilized rammed earth home.



Source: West Virginia University

Because the AHA home was built in a cold climate region, builders sandwiched a layer of insulation between two stabilized rammed earth layers to provide a highly insulative wall assembly; this method is suitable for residential or commercial building types (Windstorm and Schmidt, 2013). One major benefit of insulated stabilized rammed earth construction (sometimes called SIRE, for Stabilized Insulated Rammed Earth) is high R-values² (Windstorm and Schmidt, 2013).

² R-value is the measure of resistance to thermal conduction from one side of the material to the other; in this case, it is the temperature difference between the inside and outside walls.

Furthermore, the home was designed to have maximum passive solar heating. Energy modeling suggested that passive solar heating will satisfy 20 percent of the annual space heating requirements in the home. An innovative natural gas-fired heating system will provide for the portion of the space heating demand not met by passive solar heating. The heart of the heating system is a condensing storage tank-type water heater that provides both domestic hot water for bathing and washing and heat for in-floor radiant heating. This heating system was selected for a variety of reasons. First, because annual space heating loads and heating demand for the home are roughly 75 percent lower than average homes in the surrounding area (a function of the high levels of insulation and air-tightness provided by the building envelope), the heating system needs to provide only minimal levels of heat output to maintain comfortable conditions inside the home. Hot water heating demand, by contrast, is more a function of occupant behavior (shower length, laundering practices, and so on) and thus does not vary significantly between more and less energy-efficient homes.

Performance Validation of Aleutian Housing Authority Home

West Virginia University (WVU) has been evaluating the performance of the AHA SIRE home since its construction. The evaluation includes testing of the wall system for its structural properties in a mechanical properties laboratory at WVU and monitoring its energy use, thermal performance, living comfort, and durability at the Butte, Alaska site.

Researchers evaluated SRE from 75 specimens consisting of cylinders, beams (reinforced and unreinforced), and blocks for its compressive and flexural strengths, fatigue, freeze-thaw durability, and thermal performance. For example, researchers evaluated three 8" x 14" x 123" reinforced SRE beams designed to simulate the load carrying capacity of window lintels in Alaska in a three-point bending-shear test after two of the beams were exposed to fatigue and creep conditions that would be present in the field (see exhibit 3). Researchers also tested the SRE wall sections with several simulated earthquake loads. The result shows that walls displayed minimal deformation under earthquake load types and were deemed adequate for the specific service loads evaluated.

Researchers cycled samples for a number of freeze and thaw cycles and then evaluated them under compression to determine the loss in strength when compared with uncycled control specimens. The addition of fibers in the mix design was found to enhance the flexural capacity of the beam and its freeze-thaw durability, whereas the freeze-thaw evaluations demonstrated very promising long-term freeze-thaw durability for the building in Alaska. Thermal performance studies of the wall assembly concluded that an R-value of 40 could be achieved with two sections of SRE measuring 8 inches each with, 8-inch interstitial foam as insulation.

Exhibit 3

A stabilized rammed earth (SRE) beam being tested at WVU.



Source: West Virginia University

The mechanical property testing concluded that SRE is nearly as strong as low-strength (~2500 psi) concrete but has a near-zero impact on our environment. Highly energy-efficient rammed earth wall construction can be durable and earthquake-resistant.

Ongoing performance monitoring of the AHA SIRE has demonstrated the comfortable living environment of the home, including stable temperature and humidity and good indoor air quality. As noted earlier in the drawbacks, however, the large thermal mass of the rammed earth walls can tax the heating system of the home under certain conditions.

The AHA SIRE home has demonstrated that rammed earth construction can be adapted for Alaska. A safe and energy-efficient housing unit can be built using local materials and local unskilled labor.

Further Reading

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Acknowledgments

The authors would like to thank the leadership team Dan Duame, Steven Mandt, and Kennedy Serr at the Aleutian Housing Authority and Bly Windstorm of NAREBA for their contributions leading to the construction of the SRE house and their support to the ongoing monitoring activities. The authors appreciate the cooperation from the tenants of the SRE house for allowing us to test and evaluate their home.

Authors

Hota Gangarao is the Maurice A. and Joann Wadsworth Distinguished Professor of civil and environmental engineering at West Virginia University.

David Johnson is a graduate research assistant at the Constructed Facilities Center at West Virginia University.

Ray Liang is a research professor at West Virginia University.

Mike Blanford is a research engineer at the U.S. Department of Housing and Urban Development, Office of Policy Development and Research.

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