e3Co System: A Search for a Twenty-First Century Construction Type

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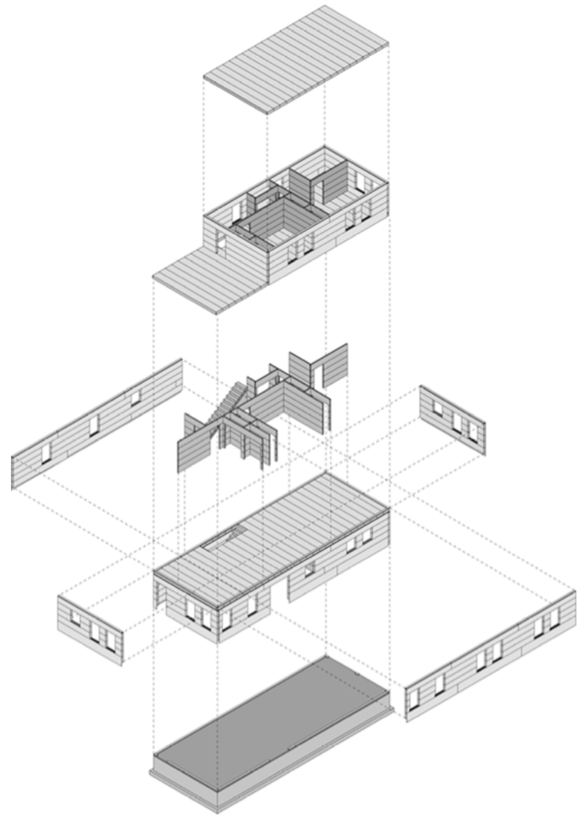

Fig. 1. Exploded diagram of comprehensive system

Project Overview

e3Co System (Ecological Comprehensive Component Construction System) is a prefabricated component building system for the complete and efficient construction of environmentally friendly, low-rise, building structures (see Figure 1). It is designed as an alternative to the relatively wasteful and laborious wood light-frame construction. e3Co System consists of long and lightweight structural insulated components that are stacked like logs in a log cabin (see Figure 2). This system will produce buildings in three stages: 1. parametric digital modeling of the building components; 2. mass customized fabrication of the building components; 3. coordinated sequential assembly of the components on site. The result will be an energy efficient building structure ready for the installation of standard interior and exterior finished surfaces, cabinets, and fixtures.

This construction system research and development moves beyond traditional scholarly research and towards entrepreneurial, market-based, product development. This investigation started out as a project proposal for an independent study with an undergraduate student. After the initial research was completed, we received a "provisional patent" for the intellectual property of this invention. Both of us legally became *co-inventors*, and we both remain active in the project development. The ultimate goal is to have this research and development of the e3Co System brought to market in the construction industry.

Project Context

e3Co System is one possible construction type among many current prototypes for the next evolutionary step of lightweight construction. Wood light-frame construction, also known as *stick-built* construction, has been in use for over 150 years with only incremental changes to the construction details. The original wood light-framing, called *balloon framing*, rose to prominence in the nineteenth century as an alternative to the cumbersome and labor-intensive heavy timber framing.[1] The lighter, two story, standardized light wood members of balloon framing could be assembled with a modicum of standard framing details. Compared to heavy timber framing, the construction of balloon frame houses did not require great skill, sophisticated tools, or a great number of laborers.[2] Instead, a crew of relative amateurs could erect a balloon frame house with a few hand tools in a matter of months. This new building technology revolutionized the construction of domestic architecture across America.

Early in the twentieth century, balloon framing gave way to yet another advancement of construction efficiency in wood light-framing: *platform framing*. Platform framing uses vertical members, or studs, that are just one-story tall, so they are much easier to handle than the two-story vertical members of balloon framing. In platform framing, a new floor platform is constructed at the top of each set of walls and constitutes a perfect work surface to construct the next set of walls for the subsequent level. Currently, platform framing can be constructed up to four stories under most North American building codes.

Structural insulated panel systems, known as SIPs, represent a significant evolutionary step for the construction of low-rise buildings such as housing or small commercial structures. SIPs are prefabricated panels with two layers of oriented strand board sheathing, or OSB, on either side of an expanded polystyrene foam, or EPS, insulated core. The building industry has long recognized the advantages of SIPs construction, including their good insulating properties and relatively short construction times required to erect a SIPs building. Current SIPs, however, have two major constructional drawbacks. One, the dimension and the weight of SIPs panels mandate the use of heavy equipment, such as a crane or a hydraulic lift, to construct a SIPs building. Two, SIPs are currently used only for exterior walls: interior partitions still need to be framed conventionally.

The components of the e3Co System, with their log-like configuration, will be of a dimension and weight that will not require special equipment for construction and will include all of the components for a complete building. The goal for e3Co System is to produce a construction type that will require only two workers who will not need specialized tools or deep knowledge of construction to produce a building structure in just a matter of days. Since heavy equipment is not required for an e3Co System building, it is a construction system that is accessible to even the smallest of construction firms or builders in developing nations that have only basic tools available.

	1'-8" H x 24' L			
	3½" EPS Core	5½" EPS Core	7¼" EPS Core	9¼" EPS Core
Lbs per Sq. Foot	3.3 lbs	3.5 lbs	3.6 lbs	3.8 lbs
Total Weight	132 lbs	140 lbs	144 lbs	152 lbs
R-Value (40°F)	16	24.3	31.6	39.9

	1'-8" H x 20' L			
	3½" EPS Core	5½" EPS Core	7¼" EPS Core	9¼" EPS Core
Lbs per Sq. Foot	3.3 lbs	3.5 lbs	3.6 lbs	3.8 lbs
Total Weight	110 lbs	117 lbs	120 lbs	127 lbs
R-Value (40°F)	16	24.3	31.6	39.9

	1'-8" H x 16' L			
	3½" EPS Core	5½" EPS Core	7¼" EPS Core	9¼" EPS Core
Lbs per Sq. Foot	3.3 lbs	3.5 lbs	3.6 lbs	3.8 lbs
Total Weight	88 lbs	94 lbs	96 lbs	102 lbs
R-Value (40°F)	16	24.3	31.6	39.9

	1'-8" H x 12' L			
	3½" EPS Core	5½" EPS Core	7¼" EPS Core	9¼" EPS Core
Lbs per Sq. Foot	3.3 lbs	3.5 lbs	3.6 lbs	3.8 lbs
Total Weight	66 lbs	70 lbs	72 lbs	76 lbs
R-Value (40°F)	16	24.3	31.6	39.9

	1'-8" H x 8' L			
	3½" EPS Core	5½" EPS Core	7¼" EPS Core	9¼" EPS Core
Lbs per Sq. Foot	3.3 lbs	3.5 lbs	3.6 lbs	3.8 lbs
Total Weight	44 lbs	47 lbs	48 lbs	51 lbs
R-Value (40°F)	16	24.3	31.6	39.9

	1'-8" H x 4' L			
	3½" EPS Core	5½" EPS Core	7¼" EPS Core	9¼" EPS Core
Lbs per Sq. Foot	3.3 lbs	3.5 lbs	3.6 lbs	3.8 lbs
Total Weight	22 lbs	24 lbs	25 lbs	25.5 lbs
R-Value (40°F)	16	24.3	31.6	39.9

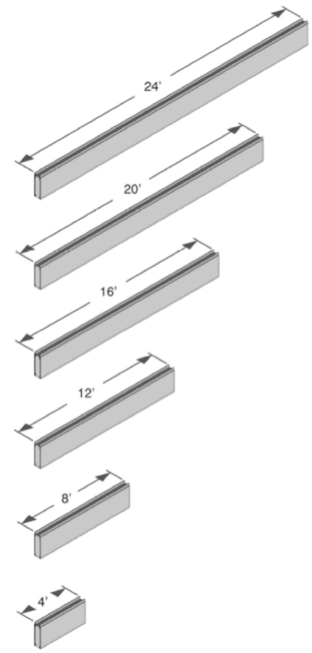

Fig. 2. Specifications of log-like components

e3Co System responds to the demands of the contemporary building market in many other ways. For example, the components are prefabricated in a controlled environment to ensure quality of fabrication and to reduce material waste. While construction costs have skyrocketed due to global demand on building materials, e3Co System will significantly reduce overall construction costs with its material and labor-efficient design. This, in turn, would allow developers to produce small-scaled commercial buildings at lower cost and more affordable housing that is needed throughout the nation. Additionally, due to its superior thermal performance, an e3Co System building would reduce energy consumption and the related production of green house gases relative to a comparable wood light-frame building.

System Components

The exterior wall components consist of two sheets of 0.4375 inch OSB on both sides of a 5.5 inch EPS foam core: the thickness of the core relates to standard lumber dimensions (see Figure 3). The total thickness on the exterior wall is 6.375 inches. OSB is a structural sheathing panel produced from renewable and recyclable wood fibers. Under pressure, the wood fibers are infused with resin binders to create a panel that is stronger and more resistant to moisture and insect damage than plywood. OSB has a maximum width of 4 feet but can be produced up to 24-foot lengths.

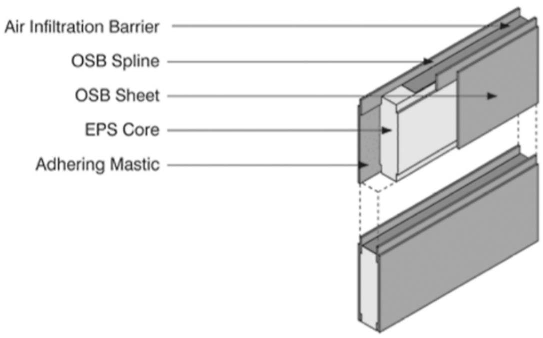

Fig. 3. Detail of exterior wall component

The foam core is made from EPS: it is a recyclable foam that is both highly insulating and structurally rigid. The insulating properties create highly energy-efficient building enclosures. The foam's structural rigidity displaces wood studs from the interior wall construction, thereby eliminating both the laborious stud construction process and the thermal bridging endemic to typical stud walls. Due to the EPS core, the thermal values for the e3Co System well exceed the current energy code requirements for comparable batt insulated wall and roof thicknesses. EPS is also mold, moisture, and insect resistant.

Exterior wall components are stacked on edge to create a continuous load-bearing wall. The wall components are 20 inches tall. When stacked, they create horizontal datums at 20 inches above the floor (a good height for window sills), 40 inches above the floor (a good height for window sills in kitchens and bathrooms), 60 inches above the floor, 80 inches above the floor (a typical door height), and 100 inches above the floor (a good ceiling height). Each horizontal joint between building components is reinforced with two 4-inch-wide internal OSB splines that are pre-attached to the back face of each sheet of the OSB sheathing. The splines project beyond the edge of the sheathing by 2 inches to create an overlap at the joint between components. The projecting splines fit into a negative space of the next component. The components are then attached by screwing through the OSB sheathing of the upper component and the projecting OSB spline of the lower component. Additionally, a flexible and compressible foam air-infiltration barrier is placed in between the two joining EPS cores. The barrier has adhesive mastic on both surfaces to bond the EPS cores together and to eliminate air infiltration at the joint.

The interior wall components consist of two sheets of 0.25 inch OSB on both sides of a 2.5 inch EPS foam core: the total thickness is 3.375 inches. Interior wall components are also 20 inches high and are stacked on edge to create a continuous load-bearing wall. Similar to the exterior walls, each joint between interior wall components is reinforced with two 4-inch-wide internal OSB splines. The adhesive barrier is also added to the interior walls: in this context, it is used to eliminate noise transference at the joints.

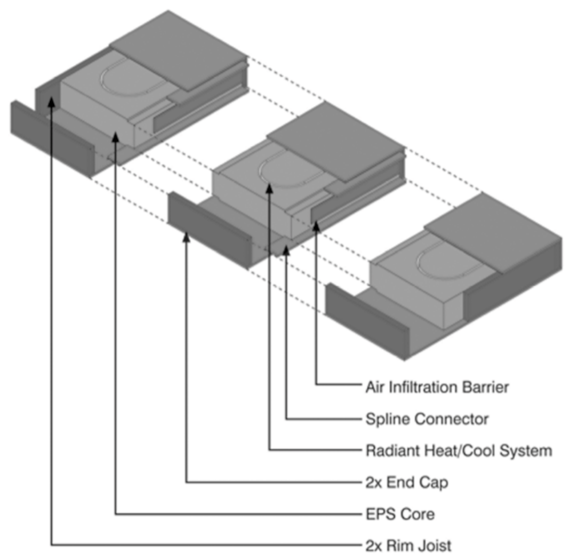

Fig. 4. Detail of floor component

The floor and roof components consist of two sheets of 0.4375 inch OSB on both sides of an EPS core (see Figure 4). Floor and roof components are 24 inches wide creating a 24-inch planning module. The top and bottom sheets of OSB act like the top and bottom flanges of an "I" beam, and the foam core acts as the web. The parametric modeling software will predetermine the depths of the floor and roof components based on their span and required thermal performance. The deepest floor and roof components can span up to 20 feet. Like the walls, each joint between components is reinforced with two 4-inch-wide internal OSB splines. The thicknesses of the EPS core vary depending on the required span: they range from 5.5 inches to 11.25 inches. The floor and roof component foam thicknesses also relate to typical lumber sizes. The overall dimensions thus range from 6.375 inches to 12.125 inches in depth.

Construction Process

The first phase of the production of an e3Co System building is the input of a building design into the e3Co System parametric software. The software will assist in determining the size and configuration of each building component including exterior walls, interior walls, floors, and roofs. Each component is a *smart part*: the parametric software predetermines all of the component's dimensions, structural requirements, details, and integrated electrical, plumbing, and radiant heating/cooling systems. The building components of the e3Co System provide complete flexibility of building configuration.

The second phase of production is the automated fabrication of all of the building components. Once the parametric model determines all of the required building components, joints, wall connections, and rough openings, the digital model will be fed into a computer-aided design and manufacturing (CAD/CAM) fabricator. The EPS foam core will be formed and cut to its required shape and then adhered to the OSB panels with a structural mastic. All locations for the field-applied fasteners will be stenciled on the surface of the OSB to facilitate the proper construction of the building. Additionally, there will be an instruction manual that will accompany the components that will describe graphically the various construction procedures.

While the simplest versions of e3Co System will be just the building structure components, the most sophisticated versions will have electrical wiring and radiant heating/cooling systems integrated into the components and ready for plug connections between components. The electrical and plumbing chases will also be identified with stencils on the surface of the OSB panels for ease of post-construction coordination. Also, we plan to adopt the current technology for a moisture barrier to be adhered to the outside sheathing of the exterior wall and roof components.

All of the required building components are then delivered to the site ready for assembly. With e3Co System, a building design is not limited to the dimensional highway regulations: the lightweight components for a building can be efficiently stacked on the back of a truck. The e3Co System will be delivered to the building site ready to be assembled on a prefabricated or site-formed foundation.

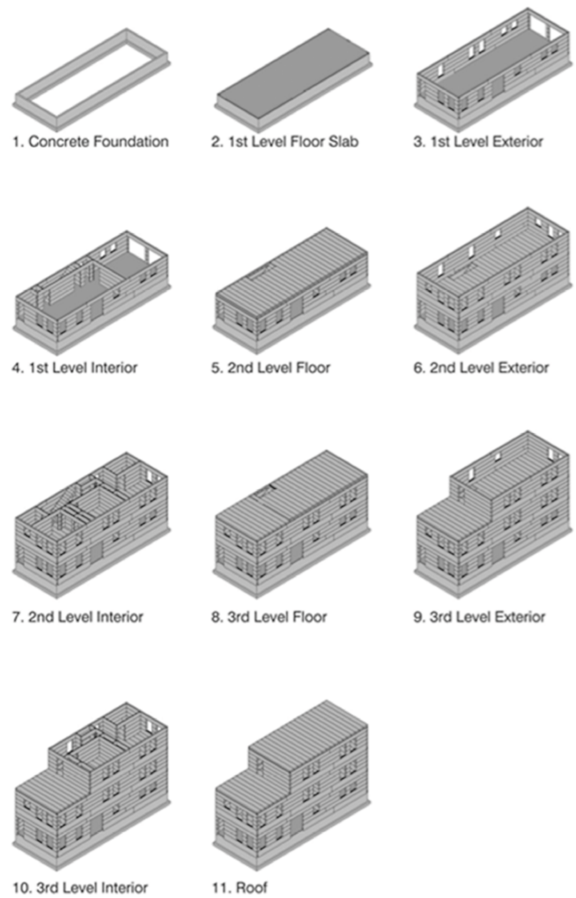

Fig. 5. Sequential assembly of components

The third phase of production is the sequential assembly of the building components (see Figure 5). Each component will be numbered so the field contractors can erect the building in its proper assembly sequence. The exterior wall components will be stacked vertically like log cabin construction. The components are attached at the joints with screws and an integral adhesive air-infiltration barrier binds the EPS foam cores together. Once the components are stacked and fastened into a wall, moisture-resistant tape can cover the joints of the moisture barrier to provide a continuous sheet of protection. Next, the interior wall components are stacked vertically in a similar sequence. The integral electrical systems with plug connections are plugged together as the components are put into position.

Once all the walls for the first level are in place, the floor components are set on top of the walls, creating a platform for the assembly of the second level walls. Similar to the electrical system, the integrated radiant heating/cooling system, also with plug connections, is plugged together as the components are put into position. This sequence is repeated right up to the final roof. Just two people with a modest set of tools will be able to assemble a complete e3Co System structure much more expediently than a crew building a comparable stick-built structure.

Project Development

The objective of this project is to bring e3Co System from concept to viable building construction product. e3Co System is conceived as economical to produce, easy to transport, and efficient to construct. It is a product for the mass market that would appeal to three primary groups: to large-scale corporate homebuilders for the multi-billion dollar housing construction industry; to large-scale building supply retailers for sale to do-it-yourselfers; to developing nations to provide durable, well-insulated shelter. Variations in the sophistication or simplicity of the system would be tailored to each user group. In its most sophisticated form with integral electrical and mechanical systems, e3Co System would be valuable to large scale housing development companies due to its expedient construction time, reduced equipment needs, and lower labor requirements. Using the e3Co System could drastically reduce the costs of a large scale housing development. In a more simplified form, the comprehensive and logical characteristics of the system lend themselves equally well to small contractors and do-it-yourself builders. It is far less complicated than conventional wood framing because there are many fewer construction details, variations, and anomalies. In its most basic form, the system could provide developing nations with a durable construction type that can adapt to a wide range of harsh environmental conditions. It can be easily transported to remote areas as a stack of lightweight components and constructed without special tools.

To demonstrate the performative and market viability of the e3Co System, we are perfecting the design of the components and fabricating full-scale prototypes. We will conduct structural testing of the panels for out-of-plane shear, in-plane shear, and flexural stresses. We will compare our empirical findings to the current structural standards to ensure that e3Co System will be compliant with building codes nationally.

There are two aspects of the e3Co System for which we plan to look for alternatives: the EPS foam core and the building foundations. The manufacture of EPS foam requires the use of petroleum based materials. Additionally, EPS is not biodegradable, so it will remain intact in landfills if it is not recycled. We would like to find an alternative to the EPS foam core to make e3Co System a more environmentally friendly product. We have not yet found a substitute material that satisfies the core's two main functions: high insulating value and structural rigidity. Paper-based products, such as honeycomb corrugated panels, do not perform as well thermally. Also, when paper products are used for building materials, the required added chemicals that are needed for fire retardation make the paper non-recyclable and potentially toxic in landfill. There are other foam products that do have good insulating value but are not structurally strong enough, such as isocyanurate or polyurethane.

We also plan to develop prefabricated foundation systems for e3Co System. Once we have done the required research and development for the foundations, we will then be able to provide a total building structure with e3Co System from foundation to roof.

Conclusion

Although this type of product research and development that we have embarked upon for e3Co System is common for other academic disciplines, such as engineering, medicine, and business, architectural faculty rarely propose new products for the construction of buildings. I have found, however, that once we have proposed a market-based research project, many options for funding and interdisciplinary cooperation have opened up within the academy. For example, the Technology Transfer Office at my university has supplied the necessary legal advice and legal fees required to register the system. The engineering school has expressed interest in assisting with the physical testing of the system with their lab equipment. Also, this type of product research moves beyond the confines of seeking grant-funding through the humanities: science and engineering grants are also potential sources. Additionally, private funding through venture capitalists is a viable way to bring this type of project to fruition.

The history of building construction systems shows a constant evolutionary adaptation to newly developed materials, manufacturing processes, and building technologies. Also, new building technics often coincide with cultural or economic demands. For example, the move from heavy timber framing to wood light framing in America coincided with an increased demand for more housing during the industrial revolution. The incremental improvements to wood light-framing over the last 150 years, however, are not enough to compete with the new technologies and current economic demands. e3Co System is an alternative system that is designed to be the next evolutionary step in the construction of low-rise buildings. Its ease of transportation and construction, its labor and material savings, and its energy efficiency make e3Co System truly a twenty-first century construction type.

Notes

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[1] Ted Cavanagh, "Balloon Houses: The Original Aspects of Conventional Wood-Frame Construction Re-examined," *Journal of Architectural Education*, September (1997), pp. 5-15.

[2] Cecil D. Elliott, *Technics and Architecture: Development of Materials and Systems for Buildings* (Cambridge: MIT Press, 1992), p. 18.