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Dear Author(s):

Enclosed is the original manuscript of your paper. Thank you very much for your contribution and cooperation.

Sincerely yours,

Wei-Wen Yu

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Enclosure(s)

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# *Light-Gauge Engineering in Today's Marketplace - The Challenges*

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## PART I - THE ENGINEERING CHALLENGE

### Current Practices

Timber harvesting in national forests, public increased ecological and environmental awareness, availability of quality lumber, timber's sky rocketing prices and a steady decline in the supply of lumber - have created a strong interest in the use of light-gauge cold-formed metal framing as a competitive alternate building material.

Cold-Formed light-gauge metal studs are manufactured from recycled steel - a more desirable and environmentally sensible alternate building material. Indeed, discarded manufactured steel products such as automobiles, air-conditioners, refrigerators, etc. are ending up as framing studs in the construction of our buildings across the country. This trend is gathering momentum. However, how we use this new material and how we allow its own identity to blossom as a viable and promising structural framing alternate is yet to be defined. In fact, the industry at large is presently bringing this product to the marketplace ignoring its structural advantages; advantages that other structural framing products have and continue to enjoy. Let us examine how metal studs reach the construction phase of a typical building project.

The Architect, being the prime design professional, customarily relies on engineering consultants for the execution of the structural, mechanical and electrical engineering efforts. During the stages of schematic design, building systems are established based on costs and efficiency. The structural engineer establishes the vertical and horizontal structural systems for the building. The Architect establishes the general assembly of curtain walls, for both interior and exterior conditions. In addition, the Architect also establishes the fire rating of the various building areas, directly affecting the nature of the structural assembly.

On such a project, light-gauge metal framing generally gets to the drawing board by either the establishment of a fire rated assembly or by the type of curtain wall assembly determined by the architect or by the architect's simple wish to use light-gauge metal framing construction. In any event, if the framing of one assembly is specified with light-gauge metal studs, it usually follows that most other assemblies are framed the same. The structural benefits of using a light-gauge metal framing

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system are seldom the reason for its implementation. However, the design of the metal stud framing system is usually not performed at this stage of the project, instead, it is assigned to the Contractor via the project's specifications which usually reads . . . "the contractor shall submit for approval signed and sealed shop drawings on the light-gauge metal framing systems, including accessories, connections and shall coordinate the work with the manufacturer for recommendations." At best, in some rare instances when roof framing is involved satisfying a fire assembly requirement, the Architect may elect to contact a metal stud manufacturer for consultation. Unfortunately, manufacturers of light-gauge studs are not geared to offer extensive engineering consultation due to the high risk and the high liability inherent with this kind of service. Therefore, the participation of a Specialty Light-Gauge Engineer at the design stage of the project is relatively non-existent today. This leaves the coordination and the problem solving stages of the project, in limbo. In light-gauge residential projects the contractor uses the metal stud as a direct substitution for nominal wood studs. Therefore, the project is built using light-gauge metal framing but following wood framing practices. As one examines this typical scenario, one sees that the design team has overlooked the contribution of the light-gauge structural engineer.

Grasping the Contractor's dilemma in preparing a bid on the light-gauge metal framing work; without documents dictating a design and without access to a consultant for technical input, can be compared to crossing a desert without any clue as to the duration of the trip, how wide the crossing, how much water and food should be carried to survive, or in which direction to go. Only one thing is clear - the desert must be crossed and upon reaching the other side, one desires a successful trip.

Despite the pitfalls; job overruns, lawsuits and the general uncertainties in which the contractor must execute his work - the Industry marches on operating this way. This attitude produces three significant drawbacks. The advantageous structural characteristics of light-gauge metal framing are not maximized and the cost of construction goes through the ceiling due to the many problems encountered with the use of incomplete bidding documents. There exists another drawback directly related to the Industry's present manner of conducting business which deserves our attention and should be of vital importance to everyone - public safety.

Under the auspices of the design-built Contractor scenario, as dictated by current trends of the light-gauge Industry, the process of engineering takes a back seat. The structural integrity of the project is virtually out of the hands of the project's design team. Instead, it is the Contractor's engineer who assumes this responsibility. A responsibility inherent with a limited sense of loyalty to the professionals of record and their design criteria. In many instances one finds a frantic Contractor battling with budgets, looking for shortcuts at any cost. This creates an environment where design drawings are not followed closely. Therefore, structural studs find themselves substituted with non-structural studs intended for interior partitions (dry-wall studs), costing much less and with lesser structural strengths. Connections are improvised in the field, bracing disappears and welding lengths shorten. In general, the project's structural integrity begins to deteriorate and with it - its structural safety.

Building officials, as a general rule, have limited knowledge in the structural design and use of light-gauge metal framing. Thus, their ability to recognize potential problems in the field during inspections is limited. The contractor is pretty much on his own - in as much as light-gauge is concerned. He can quickly cover up the light-gauge discrepancies with either gypsum board or plywood. Out of sight, out of mind and out of the eyes of visiting professionals of record who could ask questions.

**Proposed Practice**

Present practice dictates that light-gauge metal framing engineering design is the responsibility of the contractor. The design professionals of record must be given the opportunity to adequately coordinate and blend the light-gauge system with all other disciplines on the project. When this is accomplished, light-gauge will then truly become a part of the structural assembly.

In today's construction industry it is common practice for certain, very specialized, areas of engineering to have their scientific advancement, as well as their marketability, financed and promoted by specialty manufacturers. For instance, manufacturers of pre-engineered wood trusses are active participants in the financing and promotion of research, advertisement and marketing of their products. This is a task they share with many other national and international wood organizations. We have come to accept that pre-engineered wood trusses are engineered, built, and shipped to the job site by the manufacturer. Contractors can readily obtain prices for their bids which include the costs of engineering design. Engineers of record have accepted this process and even help the manufacturer with special loading diagrams on their design documents to alert the manufacturer to special loading conditions. The end result is that the contractor can provide a bid without the uncertainties borne out of lack of documentation, as light-gauge metal framing typically exemplifies today. The material, manufacturing labor and engineering costs are included in the price quoted by the manufacturer. There is no guess work; no overruns because of the unknown.

Manufacturers of the common bar joist, as well as manufacturers of pre-engineered wood trusses, handle their products similarly. Engineers of record provide, in their design documents, special loading conditions for the manufacturer of bar joists to use in their design. The list of other manufacturers who sell structural systems enjoying similar advantages is very long indeed. One wonders, when is the light-gauge Industry going to change their current practice? When are they going to reap the benefits of a similar approach for their products?

The State of Florida, recognizes that in today's highly specialized competitive world, specialties are a necessary part of the Industry. Therefore, the State has legally acknowledged several specialties in which engineering is performed under the auspices of the Specialty Engineer. The State has defined The Structural Engineer of Record as . . . "The Florida Registered Professional Engineer who develops the structural design criteria and structural framing concept for the structure, performs the analysis and is responsible for the preparation of the Structural Construction Documents". The State has defined the Specialty Engineer as . . . "A Florida Registered Engineer, not the Structural Engineer of Record, who undertakes the design of structural components or structural systems for a specific project". The areas of specialties presently defined are:

1. Prefabricated Wood Components. (pre-englneered wood trusses)
2. Cast-In-Place Post-Tensioned Concrete Structural Systems.
3. Design of Structures Utilizing Precast Concrete Components.
4. Design of Structural Systems Utilizing Open Web Joists.
5. Design of Masonry Structures.
6. Design of Pre-Engineered Structures, and
7. Design of Foundations.

The State of Florida further states that the Specialty Engineer may be:

1. An employee or officer of a fabricator.
2. An employee or an officer of an entity supplying components to a fabricator.
3. An independent consultant.

In our opinion, the light-gauge industry must launch a major program to educate the general construction and professional community in the specialty of light-gauge. The light-gauge Industry must begin the arduous task of promoting the replacement of hammers with screw guns if their product is to take its rightful place in the Industry. The light-gauge Industry must also extend their educational efforts to the universities. There the industry can prepare future generations of engineers in the arts and sciences of light-gauge engineering as a specialty. The light-gauge Industry must recognize that light-gauge metal framing, as a structural unit, must be integrated into the design stage at its inception for optimum economic design. This would ideally then become part of the design norm.

Furthermore, it is our opinion that the market has been and remains ready for changes in the manner in which light-gauge metal framing is both engineered and used as a structural system. The challenge is to bring light-gauge engineering to the drawing board in much the same manner as other specialties are brought to the design table - during the design stages of the project and not after the fact. It is most urgent that architects, engineers, contractors and manufacturers of light-gauge metal framing understand that other products have gone through similar evolutionary processes. It has been the product's manufacturer who has, through their efforts and with the support of the professional community, made a difference in selling and promoting their products. Nothing happens by itself. Light-gauge manufacturers across our country must undertake the arduous but feasible task of taking the necessary steps to place their product in its rightful place among the other recognized structural systems. Only then will light-gauge reach its full potential and evolve into a preferred alternate with the added bonus of being a recyclable product, assuring fair bidding and competition.

It is eminent that the Light-Gauge Industry prepare a business plan to provide Light-Gauge Structural services concurrent with the efforts provided by the professionals of record. Furthermore, it is imperative that Light-Gauge Engineering become a legally recognized Specialty by every Professional Engineering Regulatory Board for each state across the country. A safer, more controllable, process must be put in place and enforced to control light-gauge construction. Research and development for light-gauge metal framing must come up to par with other structural systems in the Industry. Finally, universities across our country must require, as part of their structural curriculum, the study of Cold Formed Design. Such an effort must be sponsored by the light-gauge manufacturing community. Expansion of knowledge guaranties the future of this unique structural system.

## PART II - THE ARCHITECTURAL CHALLENGE

When light gauge metal framing was first introduced into the construction industry, the focus was on replacing wood in residential construction. That was a logical step over twenty years ago, but the system has failed to evolve beyond that realm. Our environmental awareness, the depletion of wood products and technological advancements have created the avenues and need to change the way we use light gauge steel framing. The industry is challenged to explore beyond the limitation imposed by wood framing, and capitalize on the inherent structural capabilities of steel framing.

When steel first made its appearance in the construction industry the typical scenario was to re-engineer an existing wood frame structure. The potential client, an architect, developer, or owner, would submit architectural plans to the light-gauge manufacturer for a redesign recommendation using their products. The simplest and most cost effective design solution was to pull out the wood framing member (stud, joist, etc.), and replace it with the same depth steel member. A material take-off was also completed, and submitted to the client for costing purposes. The material take-off was then, and still is, vitally important to the client. This gave them a cost comparison between the two framing systems.

That scenario still holds true today. Very few structures are initially designed in steel. An exception to this is non-residential curtain wall applications. Here light-gauge metal framing is predominant because of the need for use of a non-combustible framing assembly. Codes in many areas throughout the nation have placed combustibility restrictions which must be adhered to. Wood studs simply do not meet these code requirements efficiently any longer. However, even when steel replaces wood, the wood frame design is adhere to and is very evident.

The current steel frame design has wood frame technology as its fundamental basis. Twenty years ago the majority of wood frame structures were stick built, completely at the job site. Although, this has changed somewhat within the last few years, the majority of wood structures are still constructed at the job site. The exception to this is that of wood trusses. Almost all wood roof structures are currently constructed of pre-fabricated wood trusses. These trusses are fabricated in a controlled manufacturing facility and transported to the job-site. They're cost effective, and eliminate many design concerns for the designer and builder.

Another assembly where light-gauge can be substituted for wood is in platform framing. This framing method facilitates the construction sequencing by stacking each framing system (sill, floor, roof) on the preceding supportive system. The alternate framing system is balloon framing, which is rarely used. In balloon framing, the exterior walls are installed full height and any intermediate floors are in-filled later. There are two reasons why this is no longer popular, both affect the construction sequence. First is the availability of good, straight long span wood studs; and the second is the availability of a fastening system for the intermediate floors.

The major design idiom in wood frame construction is the 16 inches (41 cm) spacing of framing members. Ironically, this concept is entrained in the industry, and its roots are not structurally derived. History teaches us that this dimension has little to do with structural design, but was an arbitrary value based on the average width of a man. The only major change in steel design was the dimensional increase to 24 inches (61 cm). This was done as an attempt to optimize the capacity of the structural member. This limitation is primarily done to accommodate the spanning capability of sheathing, and finish materials. However even with these longer spans, the spacing of the trusses is left at 16 or 24 inches o.c. (41 or 61 cm o.c.). The primary limiting factor is the structural sheathing that is currently available. The same is true for both wood and steel framing. Floor framing systems have the same spacing consideration as wall framing; and in most cases, is limited to single and double span conditions.

Wood frame technology has greatly changed over the years. Traditional wood frame construction called for a single framing member, a joist or rafter. This single member was only able to span relatively short distances. The advent of the pre-manufactured pitched roof truss, and flat floor truss has greatly revolutionized wood frame design. Now longer clear spans are available opening up greater design options. The structural designs of these elements are also made very simple for the builder or architect.

In non-residential construction, light-gauge steel framing is ideal for exterior curtain wall applications. The wall's primary structural function is to transfer all lateral loads, such as wind, back to the main structure. The standard curtain wall design falls into three general categories; simple span, multiple span, and a double cantilever. The simple span condition is where the studs are interrupted at each floor line, and is sometimes called in-fill condition. In a multiple span condition, the studs run continuously by the floor systems, and the double cantilever depicts a spandrel condition with continuous vision glazing. The roof parapet is typically designed as a cantilever off a simple or multi-span stud. The one design consideration that is constant in all the above designs is that the studs are limited to a 24 inch (61 cm) spacing. Using light-gauge instead of wood opens up a whole world of curtain wall possibilities not fully explored to date.

A quick structural comparison of a nominal 2 x 4 inch (5 x 10 cm) (actual 1-1/2 ins x 3-1/2 ins (3.81 cm x 8.89 cm) Southern Pine wood stud to a 3-5/8 inch x 0.0359 ins thick (9.21 cm x 1.0 mm thick) metal stud type "SJ" (structural joist) as manufactured by Unimast illustrates the structural differences.

Figure 1 shows two different framing arrangements. A typical wood frame and a light-gauge metal frame. Both are braced at midspan at a distance of 4'-1" (1.24 m) with an overall height of 8'-1" (2.46 m). A wind load of 90 MPH (145 KPH) has been imposed on both framing assemblies. The object is to find the maximum allowable load P which can be carried by either system using the following simple interactive relationship:

$$P/Pa + M/Ma \leq 1.33 \text{ where:}$$

Pa = allowable axial load
M = moment imposed on the stud by a 90 MPH (145 KPH) design wind load
Ma = allowable moment, and
P = the residual maximum axial load which satisfies the 1.33 interactive factor

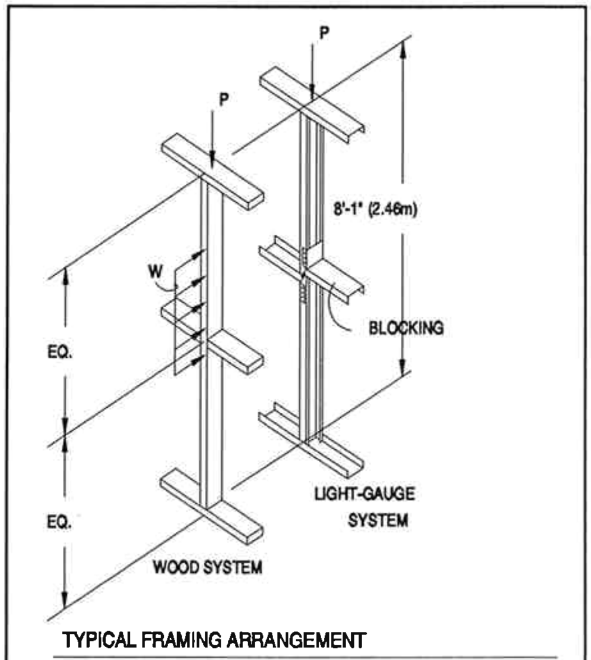


Figure 1

Table 1 summarizes the member properties and the general findings for the comparison in Figure 1. A closer look shows that the residual load of 720 lbs (3202.6 N) for the light-gauge stud when divided by the residual 304 lbs (1352.2 N) load for the wood stud yields an increased axial carrying capacity of 240% for the metal stud. Furthermore, the horizontal deflection of the wood system, at 0.467 ins (11.86 mm), is 200% more than for the light-gauge assembly. All of this at a weight of 11.5 lbs/wood stud and 7.92 lbs/light-gauge stud (51.15 N/wood stud and 35.24 N/light-gauge stud, which yields a weight ration of 1.45 or 45 % heavier for the wood stud. If one is to take the axial residual wood stud load of 304 lbs (1352.2 N) and place it on the light-gauge stud, one would find a maximum allowable acting wind moment of 444 lb-ft (602 N-m) which would translate into a stud spacing of 36" o.c. (91.44 cm o.c.) for the same lateral load !

Figure 1 and Table 1 essentially show that the maximized design capacity in the light-gauge steel stud can be shown to be at its optimum when the structural members are increased to a spacing greater than 24" o.c. (61 cm o.c.). Effective steel utilization is however limited by the structural sheathing, and finish materials that it must support. Interior gypsum panels, exterior wall sheathing, structural floor and roof products have one thing in common. Currently they can only span 24 inches (61 cm). Until alternative framing systems are developed, the steel industry will be shackled with the 24 inch (61 cm) span limitation. This is a real concern, for if these issues are not considered, the current interest in residential steel framing will wane as has occurred in the past. The true challenge for the industry, therefore, is to develop products and systems that fully utilize the capacity of the steel framing member.

One current alternative is to spread the steel framing out to 48 inches o.c. (121.92 cm). The finish materials and structural sheathing are then supported by a girt system that spans 4 feet (1.22 m). This girt system typically is composed of steel members, which are spaced 16 to 24 inches o.c. (41 to 61 cm o.c.) to receive the traditional sheathing and finish products. This has shown moderate success in certain areas, and is a derivative of the larger scale pre-engineered steel non-residential type of construction. Here the main structural component is the C-shaped metal stud ranging from 0.0359 to 0.1046 ins thick (1.0 mm to 2.66 mm thick). The girt can either be a hat shaped cross section similar to a drywall furring channel, or a down sized version of the pre-engineered steel building's Z-shaped member. Another alternative is the adaptive use of balloon framing.

One advantage of the steel stud, as opposed to using wood, is the quality that is consistent throughout the entire family of steel framing products. The members show greater dimensional consistency, and accuracy no matter how long the member is made. A twenty foot stud is just as straight and true as an eight foot member. Availability of the greater lengths is not a problem either. The design of the ledger angles, and floor system attachment details are not cumbersome in steel. When design and construction scheduling are completed, there are economies to be obtained by using balloon framing utilizing steel studs.

**WOOD STUD**

Southern Pine 2x4 nominal (5 cm x 10 cm) wood stud with allowables and Properties at 19% Moisture Content as follows:

| | |
|---|---|
| Fc ‖ =1,110 psi | (7.58 MPa) |
| Fb=1,000 psi | (6.89MPa) |
| E=1,400,000 psi | (9,646 MPa) |
| A=5.25 in2 | (33.9 cm2) |
| Ix=5.36 in4 | (223.1 cm4) |
| Sx=3.06 in3 | (50.14 cm3) |
| b=1.5 ins | (38.1 mm) |
| d=3.5 ins | (88.9 mm) |
| weight 1.4 lbs/ft | (20.43 N/m) |

Summary

| | |
|---|---|
| Pmax=304 lbs | (1352.2N) |
| δhor=0.467 ins | (11.86 mm) |

**LIGHT-GAUGE STUD**

362SJ20 of .0359 ins thick (92.08 mm x 1.0 mm thick) with a .5 in lip return (12.7 mm). Allowables and properties as follows:

| | |
|---|---|
| Fy=40,000 psi | (275.6 MPa) |
| A=0.216 in2 | (1.39 cm2) |
| Ix=0.541 in4 | (22.52 cm4) |
| Sx=0.293 in3 | (4.80 cm3) |
| rx=1.429 ins | (3.63 cm) |
| ry=0.621 ins | (1.58 cm) |
| J=0.0001 in4 | (41.62 mm4) |
| Cw=0.2986 in6 | (80.18 cm6) |
| Xo=1.356 ins | (3.44 cm) |
| weight 0.97 lbs/ft | (14.15 N/m) |

Summary

| | |
|---|---|
| Pmax=720 lbs | (3202.6 N) |
| δhor=0.231 ins | (5.87 mm) |

**Table 1**

Steel trusses have always been a challenge. Research efforts in truss design have been undertaken by several fabricators, and the result is an increased understanding and usage of steel roof trusses. There is a tremendous amount of work, research and refinement, to be undertaken, if the industry hopes to successfully compete against the well-established wood truss industry.

Research must still be pursued if light-gauge is to develop to its full potential. Fastening systems must still be researched to develop fast, efficient connections. A complain heard continually from panel shops is the slow speed of the electric screw gun. Pneumatic fasteners are the preferred method of attachment in large plants but even this does not increase the rate of production to a competitive level. The structural adequacy of the fastening system must also be researched. In some cases to meet the required structural capacity of a connection, more screws are required than can be physically accommodated. This is a critical concern which needs immediate attention.

The use of flat floor steel trusses needs to be explored. Many designers are forced to adopt a wood floor system , in a "total steel design project" instead of a steel floor system because the light-gauge floor truss has to be designed by an engineer and stick built by the contractor on site. Furthermore, the lack of available light-gauge sections to accommodate an economical design, are not available at this time. The industry is dead locked in using the C-shaped member. There is a tremendous opportunity available to the manufacturer who can research and develop a good steel floor truss system. This would require a deviation from the C-shaped framing system required for the walls. Special cross sections to accommodate the tensile and compressive forces while facilitating a fastening system should be developed. Top and bottom chord cross section could be different from each other as well as different from the individual web members. Composite design should be investigated and evaluated as a floor framing assembly.

Expansion of the girt system technology would be a viable avenue for research. Special sections for both the girts and primary structural elements could greatly increase the desirability of this option. Increased flange width of both elements would be important. The depth of the girt should be minimized to keep wall thickness down. In residential construction special detailing around door and window jambs is needed.

Although there has definitely been an increase in the number of projects that have been panelized, the standard C-shaped metal stud is not necessarily the optimum section for this kind of construction. Increased flange width would be beneficial, the lateral bracing system could be refined and the development of a fast, efficient structural fastener must be embraced. The most economical exterior system on the market today is a panelized steel stud curtain wall assembly with gypsum panel sheathing and a exterior insulation finishing system. This whole area of construction is in a position to explode with in the next few years. It's many advantages are making it the preferred mode of construction.

Another area where research is needed is in the manufacture of the steel roll. Current roll forming techniques limit the minimum size that a framing member can be made. In most construction projects short lengths (less than 6 feet in length) of material are sometimes needed. A common frustration for contractors and panelizers is the limitation on the minimum length that they can purchase. The industry needs to address this issue and maximize the availability of product lengths.

Another area of research for future construction is the development of hybrid sheathing. The envelope of sheathing design could conceivably be optimized to allow the full utilization of the steel framing member. That translates into a product than can span up to 4 feet (1.22 m). The ideal sheathing product would have increased flexural capacity to be structurally adequate in spanning 4 feet (1.22 m). Furthermore it should negate a 40% thermal reduction that is currently experienced when replacing a wood stud. Finally it should be suitable for a direct applied finish system, or be a nailable substrate for subsequent siding materials.

Some manufacturers have performed extensive research into structural clips, gusset plates and in general ancillary structural products. Additional research and development is needed to make the steel system even more simple and cost effective to design and install. As in all structural applications, the connection detail is the most important and typically most overlooked factor in the design and installation phases. Any method for making that critical area easier to understand and install will greatly increase steel's marketability.

## SUMMARY

Light-gauge has tremendous potential in the construction industry. It is a material which affords more carrying capacity per less weight. Thus less material needs to be used which leads to a reduction in labor and subsequent reduction in cost, light-gauge is a durable, recyclable product, environmentally friendly in keeping with today's concern for the world around us. It is resistant to insects such as termites, mold mildew, rotting, drying out, warping and non combustible. However the reality remains that if research and development is not undertaken soon, the window of current demand may be short lived. We must accept that steel has significant structural attributes, some of which we have yet to realize, but we must be continually challenged to improve the Industry. Some of the technology already exists and only needs to be adapted to steel. In some cases the technology itself has yet to be developed. If we are content with today's mode of business practice, we will lose tomorrow's opportunities through stagnation. The challenge is to expand our horizons and increase the viability of the light-gauge steel framing industry.