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Exposed! The Impact of Structural Materiality on the Design of Architecture

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Abstract

There is a formative connection between structural choice and architectural design. Where the term "low hanging fruit" has often been used with reference to critical first choices towards climate responsive sustainable design, a similar approach can be applied to design-thinking when it comes to structural choices. The consideration of the material nature of the primary structure at the conceptual stage of design can allow for improved focus during the design process. This is particularly critical when working with exposed structural systems as the materiality also directly impacts the aesthetics. Exposing a structure requires that the architect be significantly more technically knowledgeable in order to remain in control of the design outcomes.

This paper will elaborate an approach to instilling this type of design-thinking as it pertains to structural systems. It will look at the advantages of adopting a directed or limited structural palette in earlier design based exercises as a means of acquiring a higher level of expertise that can lead into more adeptness when dealing with the complexity associated with multiple materials. It will demonstrate that limitations can actually be liberating. Sample case studies will be used as a means to support and explore this pedagogical approach to design.

Keywords: Materials and Construction, Structures, Architecturally Exposed, Design Thinking, Pedagogy

Introduction

The last 300 years of evolution towards contemporary architectural design have demonstrated an undeniable link between the material choices we make when designing a building and its potential for excellence. There is a formative connection between structural choice and architectural design. Material understanding focusing on the ability to resist tensile and compressive forces is able to direct design choices and detailing. In departing from a technique-based historic dependency on stone, and the maximization of span through compression based domes and vaults, the technological inventions of steel, concrete and engineered timber systems have been able to realize a significantly new range of building forms and types via their relative abilities to resist tensile forces.

Where the term "low hanging fruit" has often been used with reference to critical first choices towards more passively directed sustainable design, a similar approach should be applied to design-thinking when it comes to structural choices. The consideration of the material nature of the primary structure at the conceptual stage of design can allow for improved focus during the design process and assist the decision making process. Limitations remove the "blank page" issue and can be seen to accelerate design explorations by restricting material choices. This is particularly critical when working with exposed structural systems as the materiality also directly impacts the aesthetics. Although this type of thinking initially emerged as Structural Rationalism during the 19th century, the present intentions are not necessarily as historically “formal” or classical in terms of suggesting strong impositions of symmetry in the setting out of the plan and section. The intention is simply to allow for a clearer understanding of the intrinsic relationship between materials, spanning systems, the sizes and types of spaces that they support and the resulting character of the architecture.

Learning to Expose Structure

In an age of design that is seeing unparalleled complexity, propelled by digital design tools as well as sustainable design, and that is attempting to do more with less materials, many structures are no longer able to be either simply designed or relegated to the structural consultant. Many graduating structural engineers are equally unprepared to design and detail complex structures, as such design exposure is not part of a typical civil engineering curriculum. This critical overlap of structural design thinking may be present in Architectural Engineering programs, but these programs are uncommon in many parts of the world.

Material choices can be less important when a structure is concealed as the detailing is not exposed and therefore not a part of the architectural aesthetic. The impact of material choices on design may not have been an issue in previous times when much of the structure was routinely concealed with interior and exterior finishes. However, exposing a structure requires that the architect be significantly more technically knowledgeable in order to remain in control of the design outcomes. This includes an appreciation of span limitations, fire protection requirements, fabrication methods, connection detailing and construction processes. Where is this sensibility learned? Likely not in a calculation based structures course. It is more likely acquired in a design project.

Studio projects are often program-based rather than material-based explorations. In an age of increasingly complex design, there has been a pedagogical tendency to avoid the constraints imposed by a highly formalist narrative and this seems to have largely precluded the specification of a directed structural palette within a design studio. Students are intentionally left free to explore form based on programmatic requirements. However, students often run into difficulties when attempting to apply structure (after the fact) to a project after working out spatial and volumetric relationships. This can compromise the plan, the structure and the design in a forced-fit scenario.

Fig 1: Ste. Genevieve Library, Paris (iron), TAMA Art Library, Tokyo (reinforced concrete); Scarborough Library, Toronto (timber). As can easily be seen by the above three images of libraries, materiality plays strongly into form, feeling and detailing in spite of programmatic similarities. A high level understanding of materiality was required of the architect. Photos by author.

Design studios are often sequenced from smaller buildings to larger ones as a means to increase a student’s ability to deal with increasing complexity. A similar approach can be applied to learning structural systems application and detailing. There are advantages to adopting a directed or limited structural palette in earlier design based exercises as a means of acquiring a higher level of expertise that can lead into more adeptness when dealing with the complexity associated with multiple materials.

Design Precedents

A dramatic change in architectural design, one that began to embrace structural materiality, began during the Industrial Revolution. The invention of cast iron, wrought iron, steel and reinforced concrete allowed for significant changes in structural capabilities that manifested in changes in design style. Although there were previously a multitude of “formal styles” that could be associated with western stone architecture (classical, humanist, mannerist, baroque, neo-, etcetera) the variation in appearance was largely associated with expression in the decorative stone elements and less so in the detailing of the structure itself. The exception to this would be the Gothic style as the pointed arch impacted the capabilities of span and led to the addition of structural buttressing which in turn allowed for increased levels of fenestration. That this expressed structural choice greatly impacted the architectural expression of the building would be the basis for the extrapolation into the current 21st century period that this thesis presents.

The majority of the architects whose skill in design continues to be celebrated and seen as exemplary can also be seen to have strong connections to material expression in their architecture. Structural Rationalist architects such as Henri Labrouste adopted cast iron through a curious exploration of the new material. At that time the ability of casting to incorporate a high level of decorative detail helped the public to accept the material as used by Labrouste in his two signature libraries, Bibliothèque St. Genevieve and Bibliothèque Nationale in Paris. The Italian Futurist Antonio Sant’Elia less than a hundred years later, declared a hard break with decoration and historic styles and proactively adopted modern construction materials as one of the means to achieve his design goals. These materials coincidentally did not lend themselves to decoration as part of the manufacture or construction process (in direct contrast with the decorative nature of historic cast iron). Each material would not support the other style due to their intrinsic characteristics and resulting aesthetic limitations.

“Calculations based on the resistance of materials, on the use of reinforced concrete and steel, exclude "architecture" in the classical and traditional sense. Modern constructional materials and scientific concepts are absolutely incompatible with the disciplines of historical styles, and are the principal cause of the grotesque appearance of "fashionable" buildings in which attempts are made to employ the lightness, the superb grace of the steel beam, the delicacy of reinforced concrete, in order to obtain the heavy curve of the arch and the bulkiness of marble….“ Antonio Sant’Elia 1914

Le Corbusier in his 1931 book “Towards a New Architecture” reinforces the divorce between modernity and historical styles. His exploration of industrial architecture in North America supported his focus on new materials and associated forms. Although he did not explicitly reject structural steel, the majority of his projects employed reinforced concrete, a material that buoyed his design ideas and fascination with industrial reinforced concrete grain silos. His five points towards a new architecture became synonymous with many of his built concrete projects such as Villa Savoye and Unité d’Habitation. Even as his work extended into its Brutalist phase, reinforced concrete expressed structural systems are easily seen as being central to the manifestation of his ideas.

Mies van der Rohe’s portfolio of work claimed structural steel at its center. Even as his practice migrated to North America where fire protection laws forced the concealment of his steel structures, the presence of the material was reflected in the added mullions on the Seagram Building and its many clones. Although Pier

Luigi Nervi's work included steel, it also tended towards a preference for reinforced concrete as it supported his fascination with cantilevered shapes and a complex but repetitive forming process. The ability of concrete to be formed aligned with the circular shapes of his stadia in Rome. Other modern architects also tended to focus their practice on a limited palette of structural materials. The simplicity of form worked well with the narrow range of material choices of the time alongside the limitations presented in structural design in the pre-computer era.

The High Tech Architecture of Foster, Rogers, Piano and Grimshaw introduced expressed structural steel, and with it a style whose member and connection design proactively acknowledged the force systems within. This type of architecture was slow to be adopted into what was to become mainstream architecturally exposed structural steel (AESS) as the majority of architects were incapable of conceiving of the structural design thinking required to be closely involved with this level of expression. Few engineers were also able to comprehend the intentions and possibilities of these systems. The nature of the education of both professions has still not approached a level to enable the widespread level of expertise required to confidently design and detail in architecturally exposed structural steel systems.

Global Influences

In the more global design environment of the 21st century, regional preferences or traditions that are based on the availability of materials and skilled labor will also have a great influence on structural material choices. Firms also tend to develop a focus as a function of developed expertise and success in detailing and construction. Indeed detailing and building science issues are far more challenging now than in the past as expectations of performance are much higher given the litigious nature of today. However global practices tend to explore a variety of structural materials as suits the needs and limitations of the local economies. Where inadequate local skilled labor is available, problems often ensue during fabrication and construction if materials are used that are beyond the skills of local labor forces.

Graduates must be prepared to work globally and gain experience prior to specialization. A limited palette limits opportunities. The same can be said of limiting complexity in structural design thinking. A mismatch between courses provided and design aspirations is simply not helpful and leads to insufficiency within the profession itself. It is therefore helpful in design education to ask students to fully explore and gain confidence in designing with a wider range of structural materials as it will better prepare them to adapt to requirements that fall outside of their local architectural context. Much like design professionals that become too comfortable in one material, students may not willingly take on learning to design with materials that may make a design project more demanding to detail unless such explorations are proactively supported by the supervising faculty.

Promoting Structural Design Thinking

The current state of architecture is dramatically different than it was during the past century. There is now an excessively high level of complexity that has been fueled by inventions in the areas of computing, manufacturing and materials. The simplicity presented by orthogonally based design that primarily used either steel or reinforced concrete systems is gone. Generally speaking, the nature of structural design education provided for future architects (and structural engineers) has not advanced significantly beyond what was provided during the Modern Movement. There is still a tendency towards thinking in terms of simple orthogonal systems applied to steel and reinforced concrete systems as these are easily designed, calculated and member sizes selected from prepared tables. These are often taught by structural engineers, often on an adjunct appointment, so contractually limited in their overall engagement.

It is likely neither feasible nor desired to provide architecture students with advanced structural design courses that are numerically based to address this gap. This was discussed in detail in a previous paper presented at ICSA 2013.[1] However there are ways to provide a higher level of understanding of more complex structural design issues if we incorporate project based experience. A focus on exposed structural systems, integrating the visual outcomes of the structural systems into the architectural aesthetics can provide the motivation needed to encourage students to undertake this added challenge in a design project. Repeated experience addressing detailing and member/system selection can buoy structural design thinking.

Design by Structural Type versus Program

It is also important to recognize that there is a disconnect between structural materiality and program and vice versa. As illustrated by the libraries in Figure 1, one does not necessarily infer a choice in the other. So where a design studio may base a project on a given program, as is traditionally the case, a wide range of structural materials may be suitable and not direct or inhibit the ultimate design outcomes. In the same vein, beginning a design project with a structural material does not inhibit the number of program choices and quality of the outcomes. Both present complexities in the discourse and teaching of the studio that can be beneficial. Structural design can be equally as valid a subject for exploration as program driven projects given that the structural design focused project will also have a program and demands for spatial arrangements. Designing from the perspective of structural choice is proposed to be considered as an additional lens for viewing design projects that can serve as a complementary approach to an evolution of design thinking that can include structural design thinking in a more developed and therefore, useful way.

Structural Material Selection

Given increasing pressure on teaching ratios in light of shrinking budgets, it can be problematic when students pursue a wide range of structural choices if expertise is not readily available to guide and correct. Where faculty may have been adequately prepared to advise on traditional orthogonal structural systems, many have themselves not kept up with the variety of more geometrically driven contemporary solutions. The pedagogy of this paper proposes using design projects that limit the structural materials, with a primary focus on one material, as a means to accelerate structural design thinking about that material. This also allows the faculty to expand their own understanding of new systems at a less frenetic pace. The design projects can be housed in a regular design studio or be a significant project for a course with a construction or structures focus. Again, exposed structures are preferred as they have the greatest visual impact on the design outcome.

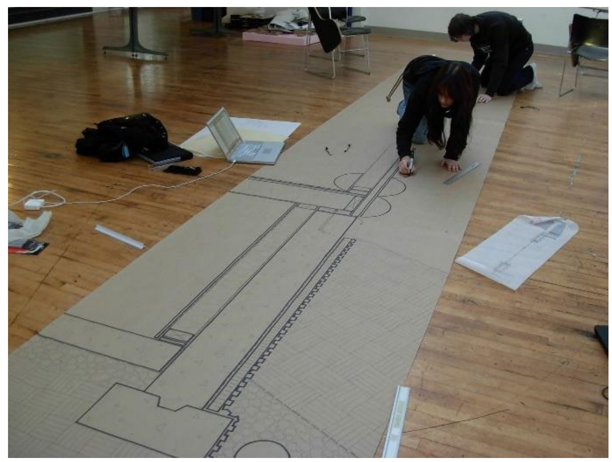
The design projects that I have thus far used to explore the validity of this approach have excluded reinforced concrete as a primary material. Reinforced concrete is permitted in an ancillary fashion for foundations and minor elements but is otherwise discouraged. The reason for this exclusion is derived from situational experience over time. Projects assigned to junior students have seen them tend to select reinforced concrete “by default” as it is perceived by them to match well the poché of their studio drawings and seems to them to require no thought as to detailing. While this may not actually be true, it seems to persist as an attitude that seems not to be discouraged in studios. That is, the studio is program and not material driven and so materiality is seldom discussed in great detail and cast in place concrete aligns well with simple modern forms and load bearing systems.

Reinforced concrete has also been excluded as a primary structural system in a comprehensive design studio for incoming masters students, the majority arriving from countries where most buildings are constructed out of reinforced concrete and so they already have this experience. Reinforced concrete does not provide them with a high level of structural learning again due to its monolithic nature and relative low level of required detailing for construction. Architects in practice are not involved in rebar placement, for instance, and much of contemporary reinforced concrete design tends to use less than challenging (or inspiring) structural typologies. The prevention of thermal bridging in cold climate buildings would be the detailed exception in this case.

Materials that are “framed” tend to provide the most benefit to structural learning. Steel and Timber systems would fall into this category. They are typically comprised of unique elements that include a choice of shape, that are assembled into larger units via connections. Most framed connections act as either hinge or pin connections and are considered determinate systems, so can even offer a link to parallel structures courses. Connections become the focus of much of the design problem as they need to transfer forces, answer to load path issues and influence constructability and ultimately, cost. Connections also feature heavily in design expression.

Design Projects Driven by Structural Materials

The first project sits as a terminal project for the first building construction course in the undergraduate pre professional degree (typically 18 year old students coming directly from high school). It is done in groups of four students and the requirement is to design a small getaway cabin out of wood frame. Although the structure in this case is not exposed, the students are required to construct a structural axonometric of the framing (thereby featuring its exposure in a way) as well as a full scale, 1:1 wall section that is drawn without cuts. The structural axonometric of a wood framed building is challenging to draw but is capable of helping students to understand the 3 dimensionality of a structural system and begins to address constructability and construction sequencing. The full scale wall section makes them aware of the scale of building materials without the expense and trouble associated with managing a design/build type project at this early stage. It also forces them to confront detailing for the first time in a manner that requires a lot of thought. It is easier to fudge details at a smaller scale and remain unaware of the relationship between materials. The attitude that I attempt to have them understand when they are making these drawings is that they are not actually creating a “drawing” but rather, a building. The type and nature of this challenge works well as an introduction to structural design thinking.



Fi. 2. First year undergraduate students drawing a full scale wall section of a small wood framed building.

The final term project for the second course in building construction is based upon a competition that is sponsored by the Canadian Institute of Steel Construction. As with most material sponsored competitions, it is expected that the material become a central focus of the design. The sponsor is looking for high quality innovative solutions. The subjects have always been very open, mostly using a single word to define the scope – cantilever, tension, bridge, span, recycle, surfaces, tower. This has been immensely helpful in permitting students to experiment with the form and forces in the structures as the program is “light”. The project is shared by the digital design course which has the added benefit of pushing their designs even further in terms of representation skills gained. That the project is housed in a course whose focus is construction both makes the material focus allowed but also presents a conflict as this is a summative project and as such should test on a wider range of expertise. In this case I am also teaching a parallel course in environmental building design where the "rest of the materials and details" can be evaluated, establishing the pair of projects as a balanced evaluation of learning.

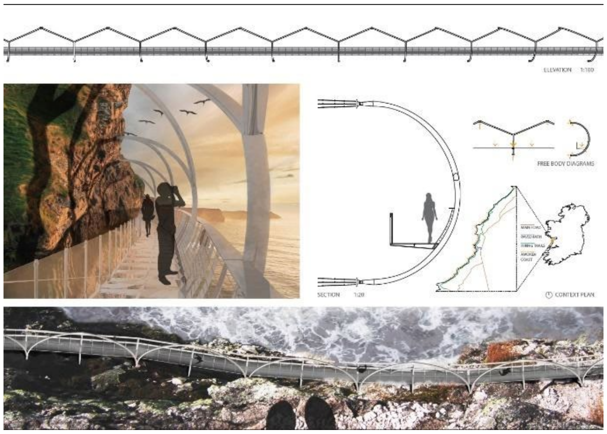


Fig. 3. The CISC Competition has been employed for over 12 years as an effective project to learn about materiality and detailing.[3]

Competitions that focus on materials can provide additional learning opportunities outside of required courses. An elective course focuses on architecturally exposed structural steel design includes a series of very detailed lectures on design and detailing that look at design impact and not calculations.[2] This course uses the CISC competition as well as the annual ACSA/AISC steel design competition. The latter is typically more program focused, so the students first complete the CISC Competition to gain proficiency in thinking about AESS details and then follow with the more program centered competition as the general difficulty level is greater. Competitions in general are a great way to add design motivation to a construction or structures focused project, taking the resulting submissions well above what might normally be expected from a purely graded element in a structures course.

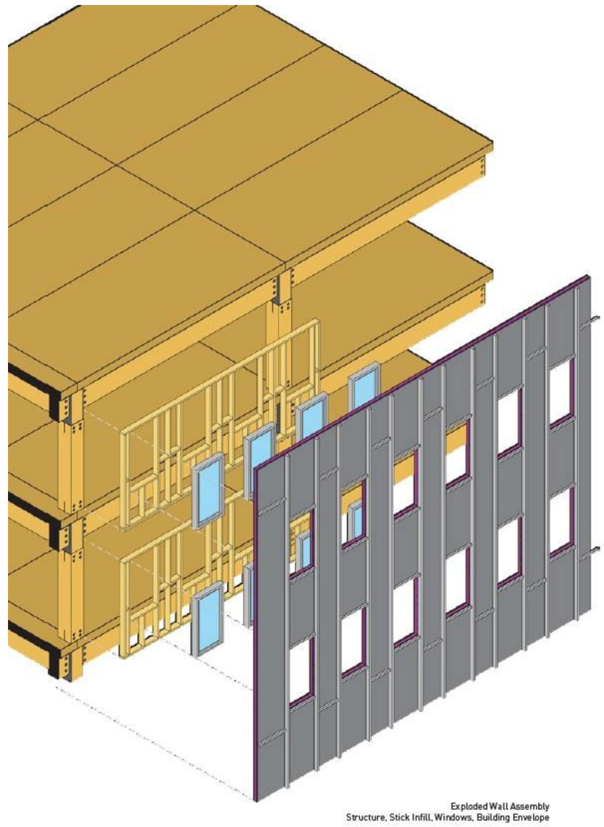


Fig 4. Project drawing of the wall and structural system from a Masters project looking at the application of CLT and glulam systems.

The Comprehensive Studio that is taken by predominantly foreign students entering our Master of Architecture Professional degree has recently mandated wood construction as the required structural system. Given the scale of the building program given, this means using glulam, larger engineered wood and cross laminated timber systems. Heavy wood systems have recently been approved for use in larger buildings in an exposed fashion provided that proper sizing and fire protection are provided. So again the potential for exposure of the wood systems add interest to the ultimate design and aesthetics of the project. Initially the move was simply to exclude reinforced concrete, as previously mentioned, but there seemed to be continued interest by the students in learning how to design and detail wood systems as they understand it to be essential to eventually gain employment in Canada. This allowed the supporting lectures to focus on providing more detailed information and feedback, and also review sessions could have feedback on this system in common so be more valuable to their learning experience.

Due to accreditation requirements, this studio has the mandate to be technically driven as well as look at program, environmental systems, envelope detailing and sustainable design. There is a parallel Technical Report course and graded element with additional submission requirements, most of which are expected to be presented during the final reviews. Of note is an axonometric drawing of the entire structural system. As with the wood frame axonometric given in first year, this is an excellent way to get students to visualize their structural systems in 3D and begin to understand the process of construction as well as stability and connection issues. There are significant elements that look in detail at the construction and detailing of the building envelope. Additionally climatic differences pose envelope detailing challenges as ours is cold, winter driven climate. There is an additional parallel required course in Advanced Envelope Design that reinforces the importance of detailing and provides a suite of detailed lectures to assist with this subject matter. Although our own undergraduate students also take a Comprehensive Design term, it is run in a more open fashion as far as materials and detailing is concerned. They have had numerous previous courses and cooperative education experiences with which to prepare for the detailing demands of this term. The Masters studio for our external students needs to take a somewhat "catch up" approach to level up some of their technical skills as pertains to cold climate and Canadian design standards and expectations.

Fig 5. An interior rendering of the Masters level project showing a high level of engagement with the materiality of the glulam and CLT system and the impact of its materiality on the aesthetics of the space.

Conclusion

Design exploration is not a studio exclusive project type. This paper asserts that students can benefit in terms of structural learning by also incorporating project based work that requires a focus on a limited palette of structural materials. This is seen to be able to allow for a focused experience that can result in a much deeper understanding and appreciation of the relationship between the relative capabilities of structural materials and the architecture that they support. This type of design thinking supports a comprehensive learning experience.

Notes:

1 Boake, Terri. The Dynamic Phraseology of Structures: Enabling the Design of Complex Systems. ICSA Conference Proceedings, 2013.

2 Website and course information for Arch 570: Architectural Steel Design. http://www.tboake.com/AESS_winter2018.html

3 Canadian Institute of Steel Construction Student Design Competition. https://www.cisc-icca.ca/architecture-student-design-competition/