THE UTILITY OF STRUCTURAL ENGINEERING CONCEPTS IN ARCHITECTURAL THINKING: THE IRANIAN EXPERIENCE

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Abstract
This article explores the utility of structural engineering concepts in the architectural design process. The widening gap between architects and structural engineers who pursue divergent intentions during the design process prompted this research. While the architects lament the insensitivity and unfamiliarity of structural engineers towards shared values such as aesthetics, the structural engineers criticize the architects for their lack of essential structural engineering knowledge. Analyzing the data collected from in-depth interviews with twelve renowned Iranian architects/engineers reveals the nature, outcome, and content of structural engineering concepts, which can be found useful to architectural education and practice. The interviewees used metaphors to describe the nature of the relationship between architecture and structural engineering. They also encouraged architects to integrate the building’s structure into its architectural design as part of a cohesive design process rather than two separate systems managed by different disciplines.

Keywords: architectural design; structural engineering; pedagogy.

INTRODUCTION
Against the backdrop of two universal schools-of-thought in architectural pedagogy, namely, ABET (the Accreditation Board for Engineering and Technology), which gives architecture an engineering focus, versus RIBA (the Royal Institute of British Architects) with more emphasis on artistic skills, this article critically evaluates the utility of structural engineering concepts in architectural design thinking. It explores this question by surveying 12 renowned Iranian architects and architectural educators. While prior to the 1979 revolution, Iranian Universities developed and crafted their own programs they now carry out a set of standardized and centralized curricula for all the undergraduate and graduate disciplines. The nature, outcome, and content of the relationship between architecture and structural engineering capture the findings through which their linkages can be explored.

Familiarity with engineering concepts is imperative for architects and ranges from basic to rigorous calculations of structural elements (i.e., beams, columns, walls, foundations). The key question is: to what extent and in what ways can architects expand their understanding of these concepts without facing the information overload, recitation of concepts without understanding them, or trying to mimic what structural engineers do? There is also the question of practicality and collaboration between architects and structural engineers. A study on the quality of collaboration between architects and structural engineers, reports that while architects expect engineers to engage more, and embrace creative architectural design ideas, structural engineers expect architects to understand the structural concepts and seek advice before it is too late into the design process (Charleson and Pirie, 2009).
These concerns call for exploring the ways in which familiarity with structural engineering concepts could inform architects toward problem-solving—especially in the initial stages of design. These questions become particularly relevant since two divergent pedagogical approaches dominate the architectural training. While the traditional French Beaux Arts school-of-thought and RIBA adhere largely to artistic design principles more so than engineering calculations, architecture engineering programs focus instead on construction management as an offshoot of engineering, and on engineering principles rather than artistic content.

The article is organized into four parts. It first presents the research method and research questions, followed by an overview of the literature on the professional relationship between structural engineers and architects captured by two divergent pedagogical approaches to architecture (ABET and RIBA). The next part presents an overview of the architectural education in Iran and the extent to which 12 renowned Iranian architects/engineers found structural engineering concepts useful in their design practices and teachings. The third part focuses on the nature, outcome and content of the relationship between architectural design and structural engineering concepts, which emerged as the recurrent themes from the content analysis of the conducted interviews. The interviewees used metaphors (i.e., the nature, human embryo, organisms, and ecosystems) rather than abstract formulations to conceptualize forms and structures integrally rather than thinking about them separately. To do so in practice, they advised to rely more on intuition, common sense, and observation. These examples capture the key ideas behind each of these three emergent themes respectively. The article ends with the concluding remarks.

RESEARCH METHOD
This research stems from the need to revisit the architects' perceived responsibilities (i.e., creative design thinking) versus those of the structural engineers (i.e., calculating the structural elements such as columns, beams, and footings). Since architects are expected to design buildings while delegating the more technical and engineering-related tasks to structural (civil) engineers they may not think holistically toward their designs, and typically lack the skills that would allow them to think of designs unifying architectural and structural systems. Hence, architects need engineers as consultants who may alter the original design concepts based on structural rather than aesthetics considerations.

Using qualitative methods, the data for this research was collected from face-to-face interviews with twelve well-known Iranian architects/engineers who have taught in major Universities, and have a long track record of professional practice (in some cases for 40-50 years). The interviewees signed an informed consent before interviews were conducted. The Interviews were conducted in Farsi at the interviewees' consulting firms in 2011, and on average each took 90 minutes. The interviewees have served as experts and jury members for major architectural competitions, and collaborate with international architectural organizations such as the Agha Khan Architectural Award.

Most interviewees own consulting architectural firms, and have designed major buildings both in Iran and overseas. For example, Diba has designed the Iranian Embassy in Germany; Kalanatari has designed the Iranian Embassy in the Republic of Georgia, and Zeinoddin has designed the Iranian Embassy in Japan. Saremi has designed several buildings including the Azadi Theater (1998), and the Molana residential project (2000). Hariri has among other buildings designed the National Budget Building in Tehran, while Saed Samiee has designed the Central Library of Zanjan University. Ghanei has designed the Sports Complex in the City of Naian. Arfaei has designed the award winning Jami Mosque in Bandar Abbass.

In addition to copious notes, the interviewees filled out a questionnaire during or after the interviews and submitted evidence (i.e., free hand sketches) on the use of structural engineering concepts before proceeding with technical calculations of their buildings. Except for those trained as structural/civil engineers, all other interviewees stated that they use freehand sketches in the
initial stages of architectural design, and submitted sketches of their implemented projects ranging from high-rise buildings to embassies and libraries. Besides characterizing the relationship between architecture and structural engineering the interviewees also commented on the quality of the structural engineering courses they took in college, and the extent to which they found those courses useful for professional development. Content analysis followed data collection whereby the respondents’ key words/concepts were identified and coded (Miles and Huberman, 1984). See Table 1.

In addition to years in practice and teaching the interviewees addressed the following questions:

1. Whether they used structural engineering concepts in their architectural designs/courses?
2. If yes, specify and attach these ideas both in narrative and graphic (sketch) forms
3. Identify built examples which illustrate the use of structural concepts in projects/courses
4. Discuss the degree to which the courses they took or taught in structural engineering were useful in architectural design?
5. Recommend how to improve the content of the courses related to structure for architects?
6. The extent to which they find abstract structural engineering concepts useful in the architectural education?
7. To what extent they find practical experience useful for architects?
<table>
<thead>
<tr>
<th>Name</th>
<th>Specify structural engineering concepts in your designs</th>
<th>Built examples of using structural concepts in design</th>
<th>Usefulness of structural courses in architectural curriculum?</th>
<th>Professional experience vs. architectural training</th>
<th>Suggestions</th>
<th>Use of Metaphor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheikh Zeineddin</td>
<td>Building elements reflect structural forces (arches, columns, walls)</td>
<td>Iranian Embassy, Japan</td>
<td>Not useful</td>
<td>Problem solving with experience rather than abstract courses</td>
<td>Integrate aesthetics with structural necessities in cultural context</td>
<td>Forces of nature</td>
</tr>
<tr>
<td>Saremi</td>
<td>Understand the forces of gravity, use of walls (thin, thick, etc.)</td>
<td>Bolur Tower, Tabriz, Afsahar Residence Tehran, Villa, N. of Iran</td>
<td>Not useful</td>
<td>Intuition, self-discovery</td>
<td>Construction lab, practical training (e.g., carpentry and welding)</td>
<td>Tree, nature, mathematics (complexity, observation, integration, inspiration)</td>
</tr>
<tr>
<td>Diba</td>
<td>Integrate vernacular and modern architecture; high tech arch., Iranian architectural heritage</td>
<td>Iranian Embassy, Berlin, Bank Maskan Kerman, Iran</td>
<td>Not useful at all, most architecture programs suffer from lack of integration between arch. &amp; structure</td>
<td>Self-discovery, observation, experience, architecture is like “fetus;” importance of finishing in architecture</td>
<td>Revamp architecture curriculum; field trips</td>
<td>Turtle, rose, egg, fetus, jaguar, morphology, ethics (integration, stability, flexibility, speed &amp; structure of jaguar)</td>
</tr>
<tr>
<td>Arfaei</td>
<td>Integrate architecture and structure (e.g., the pyramids)</td>
<td>Bandar Abbass Jami Mosque</td>
<td>Not useful</td>
<td>Mentorship of “expert knowledge” by “local knowledge”</td>
<td>De-emphasize purely abstract structural concepts to architects</td>
<td>Vernacular architectural forms (i.e., cisterns and wind catchers)</td>
</tr>
<tr>
<td>Hashem Nejad</td>
<td>Folding, Deconstruction, geodesic domes, IM Pei’s Louvre, Foster’s Bank</td>
<td>Residential</td>
<td>Conditional</td>
<td>De-emphasize abstract concepts; increase students’ understanding</td>
<td>Use of design software; understand basic concepts (i.e., stability design)</td>
<td>Building design vs. architecture (imageability)</td>
</tr>
<tr>
<td>Ghanei</td>
<td>Soleil; double-skinned facades, Iranian architecture; cultural legacy; IM Pei’s Louvre project combines simplicity and practicality</td>
<td>Sports complex, Naein; Arts Garden (Baghe Honar); Isfahan, Water Hall, Absar</td>
<td>Important practical &amp; sensual understanding</td>
<td>Prevent visual clutter</td>
<td>Simplicity, cultural sustainability, practicality</td>
<td>Organic and green architecture; integrate landscape and architecture; organic forms; American Indian tents; “A” shaped forms of water cisterns; pyramids; Arab women’s outfits to promote sustainability</td>
</tr>
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</table>

### Table 1. Summary of respondents’ answers to research questions (Source: Interviews).

**STRUCTURAL ENGINEERING VS. ARCHITECTURE**

The relationship between architectural design and structural engineering concepts in the West provides a backdrop to the Iranian experience explored here. The industrial revolution separated...
the old from the new age during which new technologies transformed the civil society and public perception toward mass production and standardization (Ben-Joseph, 2005). Architects of the new era kept pace with the realities and demands of the society. The Bauhaus and the International Style envisaged new responsibilities for the social relevance of architects, who as artists were largely protégés of influential political and religious leaders of their communities a century earlier (Kreditor, 1992). These responsibilities stemmed from the applications of new technologies, the beginning of the professionalization of architecture, and a tendency for training engineers rather than artisans and craftsmen. Hence, structural engineering evolved from architecture as craft into a by-product of scientific rational thinking, and gained new grounds as a separate discipline seeking new identity.

Further specialization and advances in construction techniques drove a wedge between architecture and structural engineering (Cuff and John Wriedt, 2010). While until the 19th century the master builder assumed full responsibility from architectural to structural design, thereby, envisioning and creating a balanced coherent outcome, architects now design buildings without much engagement in other pragmatic skills including construction and fabrication (ibid). These responsibilities have caused problems whereby the architect is accountable for the artistic part and the structural engineer for the structural part. This creates an imbalance in the design process preventing a coherent and holistic architectural design. Two popular schools-of-thought in architectural design addressed this imbalance. Unlike the French Beaux-Arts architectural pedagogy, which focused on honing students’ visual skills and emphasis on proportion and scale, the Bauhaus training emphasized apprenticeship and gaining mastery of crafts such as carpentry and masonry as well as reconciling between arts and construction (Giedion, 1962).

Whereas innovations in the structural engineering sciences gradually intensified the rifts between architectural and structural engineering innovations in architectural design do not seem to catch up with them. The chasm between structural engineering and architecture makes the potential collaboration between the architect and the civil engineer challenging and less conducive to acceptable outcomes. The advent of modernity exacerbated the situation by further specializing architecture and engineering, and hence, limiting the familiarity of architects with a comprehensive knowledge of structural engineering concepts. Regular training courses set up for engineers and architects in various countries attest to the further specialization and professionalization of scientific disciplines as a global emerging phenomenon.

Debates surrounding innovative structures and technologies reflect sharp boundaries, which have also defined contemporary academic disciplines. Consequently, recruiting knowledgeable experts with catalytic roles in training structural concepts to architects has become increasingly problematic. In many cases, civil engineers undertake to teach these concepts to architects. However, the degree to which architects find such courses effective remains questionable while finding qualified architects who can teach them is fairly uncommon.

Structural engineering concepts transcend solutions to common structural problems and range from addressing structural forces to symbolizing aesthetic values. For example, construction technology in Norman Foster’s work has become a potent architectural vocabulary for spatial expression. Indeed, structural thinking can provide architects with numerous possibilities from conceptual to detailed design. But the dilemma is that during this process, distinguishing between architectural and structural design becomes somewhat murky (Afshar-Naderi, 1996). Calatrava’s projects, typically demonstrate creativity in both areas. At the implementation stage and subsequent to the specification of structural systems architects feel more comfortable to take advantage of myriad ways of finishing interior decoration and spatial arrangements. Ignoring such information is analogous to a poet with a limited vocabulary, or a conductor who does not quite capture the range of his musical instruments to contribute to the entire orchestra (Hashemnejad and Soleimani, 2007).

While the knowledge gap between architects and structural engineers has widened, their responsibilities often overlap. For example, architects can inspect structures of up to two stories while structural engineers are allowed to design such buildings. This confusion and confounding
responsibilities promotes competition rather than collaboration between architects and structural engineers. The divergence of these two disciplines owes much to their specialization and separation of responsibilities. Reconciling this schism prompts searching for an effective collaboration between architects and structural engineers. This collaboration requires the architect to have a realistic understanding of the uniform structural behavior without the need for rigorous structural calculations.

**ABET VS. RIBA**

Two divergent trends distinguish the architecture curriculum today: ABET vs. RIBA. Whereas ABET views architecture as a sub-discipline of Civil Engineering (CE) RIBA considers it a separate profession. Often times, “many prospective students do not understand what architectural engineering is and are confused as to how it differs from architecture” (American Society for Civil Engineering Education, 2007). Substantial overlap among the courses offered in each discipline perhaps accounts for this confusion. In many of the 17 accredited Architectural Engineering (AE) programs in the United States, the AE and CE students attend the same classes with the same instructors. Content wise, both the AE and CE programs emphasize “the area of structures” (ibid.). The majority of the AE programs in the U.S. take four to five years with the average credit hours in the former range from 126-138 and from 158-165 for the latter. Proficiency in mathematics, statistics, strength of materials, calculus-based physics, and general chemistry, fluid mechanics, dynamics, and other engineering-related courses emphasize the requirements for the AE students as reflected in the ABET accreditation criteria. Emphasis on engineering courses, therefore, does not leave much room for the design-related courses as the architects’ main professional concern. In fact, the curricula of most accredited AE programs in the U.S. focus on: communications (i.e., writing and technical presentations); humanities (i.e., political science and economics); math and science (i.e., calculus, statistics, differential equations, chemistry, physics, and computer science); engineering science (i.e., statics, thermodynamics, and fluid mechanics); structures (i.e., structural analysis and soil mechanics); electrical/mechanical systems (i.e., lighting, acoustics, and environmental controls); construction (project management, contracts, and specifications, construction materials, construction methods, and estimation); technical electives; other (i.e., physical education, engineering economics, professional practice and surveying); architecture (i.e., architectural design studio and history of architecture); capstone design (i.e., senior design project) (ibid).

RIBA however, has a different take on architecture and concentrates on five areas (www.architecture.com, the Royal Institute of British Architects): professional context (i.e., architectural design, sustainable design, and design for access); practice and management (i.e., business administration and marketing); managing projects (systems of structuring and managing the brief process, negotiation skills, and contracts); construction skills (i.e., innovation in building materials and construction products); and personal skills development (i.e., verbal, critical, and interpersonal skills).

These two approaches underline different skill sets, competencies, responsibilities, and professional identities for architects. While an architectural engineer has limited design capabilities a RIBA-trained architect is a designer with a limited understanding of structural systems, but can engage in technical dialogs with engineers. This dichotomy between architecture as a sub-discipline of CE vs. an independent discipline which both derives from art as much as sciences has grown over time, and has made the prospect for creating a balanced curriculum unlikely. This wedge clearly manifests the struggles architects face throughout their training.

Iranian universities are no exceptions, and the conducted interviews reflected their opinions about the architects’ competencies. In many cases, they lamented the abstract notions of structural engineering as prescribed in the AE curriculum. They proposed instead, a balanced training in which observation and profound in-depth understanding of the natural phenomena provide grounds for developing a savvy for integrating architectural design with structural insight.
ARCHITECTURAL EDUCATION IN IRAN

The architectural education in Iran pre-dates the 1979 Islamic Revolution. Three major Iranian Universities offer degrees in architecture (Tehran University, Shahid Beheshti University, and the Iranian University of Science and Technology or Elm'o Sanat in Farsi), each of which has contributed to architectural training for over forty years with Tehran University (with over seven decades) being the oldest. The three universities offer B.A. in Architectural Engineering, M.Sc. and Ph.D. in Architecture. Energy, project management, landscape architecture, architectural engineering, historic preservation, history of architecture, building construction and technology, and urban planning represent the major areas of concentrations in those programs.

While Iranian universities had separate curricula prior to the Revolution, they adhered to the academic programs prescribed by the Cultural Revolution Headquarter after 1979. That headquarter standardized the content of architecture program based on what it considered the essential competencies of architects apropos of Iran’s cultural, social, and technological characteristics. The approved curriculum places much emphasis on the architects’ technical competencies and capabilities in statics, steel and concrete, and building technology. However, they differ in how to familiarize the students with imperative technical competencies.

Special attention has been given in recent years to natural and organic forms and integrating architectural and structural compositions, best exemplified in living organisms and animal anatomies. In the exhibitions series at Shahid Beheshti University College of Architecture and Urban Planning (http://archurb.sbu.ac.ir), in addition to such forms, students produce models based on the Japanese art of origami. These series demonstrate innovative approaches in familiarizing the students with complex architectural/structural compositions; a less orthodox approach in understanding structure as complementary to architectural design. Attention to nature, both as form-giver and a source of design inspiration, has indeed, prepared students to be more creative than their counterparts in the other architecture programs. Special tributes were also made to engineers such as Peter Rice, Santiago Calatrava, and Buckminster Fuller who bridged the gap between architecture and engineering with their contributions to innovative architectural expressions.

EMERGENT THEMES

Three common themes emerged from the in-depth interviews about the relationship between architecture and structural engineering. The first theme reveals the nature of this relationship metaphorically rather than explicitly. Unlike the engineers’ reductionist approaches architects think about the form-structure relationship metaphorically and instinctively.

The interviewees also discussed the relationship outcome and considered the separation of architectue and structural thinking unnecessary while believing that abstract calculations subsequently makes sense for purely practical and implementation reasons. Seen thus, to architects architecture manifests a monolith that integrates construction materials, structural system, and stability. The third pattern focused on the content (i.e., the local vs. expert knowledge) of the relationship. Each theme unfolds one aspect of the relationship between the two fields, and in toto, they outline three ways to conceptualize their integration rather than seeing one as an offshoot of the other, or as an afterthought.

Nature

The interviewees used metaphors to articulate the nature of the relationship between architectural creativity and structural engineering. Metaphors enrich and enable “the currency of the artistic imagination” (Watson, 1984). Architects learn from the ‘nature’ as a potent metaphor even though its definition and whether it is “credited to divinity or to biological evolution” remains disputed (Sommer, 2010). Ghanei underscores the importance of organisms and ecosystems in form-generation. Natural forms inspired the primitive structures of the pre-historic period. To seek protection against natural disasters and to address basic needs pre-historic men took
advantage of their resources. Trees, cliffs, and caves protected them against wild animals, and large pieces of timber were used for transportation purposes and crossing rivers. Using natural forms and the nature as a model for technical inspiration and perfection gradually transformed the pre-historic man from novice to expert. Nature informs architecture, says Hariri, and to survive, structures should be strong and stable. Kalantari considers rhythm and dynamism relevant metaphors in architectural thinking. Natural organisms exemplify unique structures and forms, which allow them certain affordances, degrees of freedom, and flexibility.

According to the interviewees, simplicity (Hashemnejad), complexity (Iravanian), symbolism, balance, stability and harmony reflect multiple attributes of the nature of the relationship between architecture and structure (Figure 1). Architects, interviewees argue, can detect these relationships by intuition and making astute observations. Diba uses the fetus to show the inseparability of structure and architecture and how art, environment, and nature collaborate in its growth. Otherwise, a defective fetus cannot grow to embody a healthy human being. Imitating the laws of nature raises the architects’ general awareness and inspires them toward innovative designs. Trees illustrate how natural forms inspire architects to generate forms that demonstrate stability, aesthetics, and firmness. The Bird’s Nest—another meaningful metaphor—accommodates to sports activities. The laws of nature also serve as a good role model for architects. Hurricanes and floods illustrate the transfer of the forces of nature through resistance (i.e., wind or other flows). These forces guide architects to act intuitively and seek to learn from natural growth mechanisms.

Modeled after nature Faridani has developed a unique teaching style, which strengthens the students' hand-to-eye coordination and a sense of scale. He uses metaphors to articulate the relationships between scale, structure, design, and morphology. For example, he stresses the importance of model building in creative and critical thinking for architects. As a useful tool, a mesh illustrates the distribution of stress and strain in structural elements. The students use a large fishing net to erect a mesh. Using 200 balloons the mesh was partially suspended in the
air, while deadweight was used to keep the mesh downward. The upward and downward direction of the mesh alters its original stasis. The areas of the mesh under stress and strain become more like diamonds rather than their original squares. This experiment exemplifies a useful way to communicate to students how to conceptualize hybrid or complex forms found in nature. Others have used similar approaches in architectural design thinking. For example, in “bio-structural analogues in architecture,” the role of “animal,” “coral,” “seashell” analogues as various experimental means to enhance technological thinking in architectural studios has been extensively discussed (Lim, 2009). Building models based on these natural and biological organisms helps the students to visualize complex forms without the need for tedious abstract mathematical calculations. The human body (i.e., inhaling and exhaling through the lungs as a useful model for sustainable building design), Faridani believes, portrays another useful model for design-structure thinking.

The interviewees generally stated that the structural engineering courses in the architectural curriculum of Iranian universities are not useful in their current form. These courses mainly focus on abstract concepts (i.e., moment, torsion, tension, or compression) formulaically and through abstract calculations. There was consensus among the interviewees that teaching abstract engineering concepts without being grounded in the real-world examples does not promote critical and creative thinking. According to Zeineddin, the transfer of structural engineering concepts to architecture students requires continuous, gradual effort, instead of using hard core calculations; something “average” architectural educators and mentors do not commit to. Faridani also stressed his unique approach which involves gradual yet constant immersion of students in practicing architecture and structural engineering.

To remedy this deficiency, interviewees argue, architects and especially architecture students should simulate natural forms, hone various skills through field trips and observation, work with different construction materials such as timber, concrete, and steel, and practice carpentry and welding. Zeineddin finds the common abstract problem-solving techniques in architectural pedagogy less useful or indirectly relevant compared to seeking other approaches including self-discovery, observation, and critical thinking, and acknowledges the role of experience in shaping an architect’s professional identity. He likens experience to a ladder in which a novice architect can climb up over time. Interviewees also consider architectural forms resulting from architectural expression with incoherent structural systems partially responsible for poorly designed buildings.

These remarks do not deviate much from those who lament the use of abstract engineering concepts and technical calculations for architects. Golabchi reiterates this point and refers to his own publications where he discourages architects from adhering to technical calculations. Instead, he calls for a deeper understanding of forms where they follow or result from aesthetics, functional, or service-related rather than purely structure-related imperatives. These remarks resemble the pedagogical imperatives of those who address the knowledge gap between architects and structural engineers through potent graphics and brief descriptions instead of lengthy calculations. Introducing abstract structural logics has graphically enhanced the engagement of architects and engineers in shared dialogs. Some for example, discuss the interface between structure and form in two- and three-dimensional shapes, whereas post and beam, curved arch, pitched roof and barrel vaults illustrate the former, air supported, membrane and mast supported structures showcase the latter (Silver and McLean, 2008).

Outcome
Integrating form and structure illustrates the outcome of the relationship between the two fields. To Saremi, Ghanei, and Zeineddin, the nature integrates “simplicity and complexity” into “efficiency, flexibility, stability, and adaptability.” Ghanei believes that simple structures created by American Indians exemplify how architectural functionality integrates structural thinking (Figure 2). The typical water cisterns or ab anbars (in Farsi) also depict such integration.
Simplicity and intuition rather than complexity serve useful to think about integrative outcomes. Simplicity can be achieved in different ways, like how fingers, the forearm, and the joints play integral roles in the functionality of the human arm. Geometrical forms (i.e., cubes, cylinders, pyramids, or spheres) can accommodate various functions and prove more useful in design thinking compared to irregular, complex, and composite arrangements which lack identity and functional-formal clarity and simplicity (Kasprisin, 2011). Well-designed and well-balanced buildings demonstrate the unity and harmony of architecture and structural form. To promote creative thinking in design students should avoid using complex forms (Shahroudi, et. al., 2009). In contemporary architectural training simple geometric forms help students understand unity and stability, while any attempt to disturb the purity of architectural composition could disturb both the building’s form and its functionality. Excessive use of complex forms increases ambiguity in the building appearance and allows the technology to reign over architectural spirit and meaning. The majority of interviewees underscored this point by showcasing the works by Le Corbusier, Mies Van der Rohe, Renzo Piano, Daniel Libeskind, Norman Foster, Santiago Calatrava, Pier Luigi Nervi, and I.M. Pei whereby structure and architecture are integrated not imposed.

The importance of simplicity in architecture—especially with regards to structural engineering concepts—is not unprecedented. ‘Less is more’ captures a common attribute of simplicity—especially in an era characterized by the proliferation of computer-generated forms—where technical prowess rather than need alone derives architecture. But simplicity by no means ought to determine the quality of the spatial experience. Indeed, as a powerful conduit towards creativity, integrating architecture and structural engineering through simple forms may result in the complexity of experience. Hence, instead of conceptualizing simplicity as merely the process of reduction by “leaving things out,” it can foster “forms that read as simple although incorporating a world in themselves, like the residue of past eras trapped in amber” (Treib, 2007).

Faridani also stressed the utility of first-hand experience in architectural model building instead of abstract calculations. A somewhat surprising comment regarding simplicity pertains to Golabchi who is a civil engineer by training. While as an engineer who believes that “form follows forces,” one would expect him to stress the role of technical computations or abstract structural
engineering concepts in the architectural training, instead, he believes that structural concepts should derive from "functional, aesthetic, serviceability, and construction" imperatives (Figure 3).

![Incubator Building project, Isfahan, Iran; the natural landscape informs the building form and its structure in Ghanei's architecture (Source: Authors).](image)

To Golabchi also, the integration of architecture and structure results in formal and structural stability as well as balance and harmony. Zeineddin argues that the forces acting upon the structure of a building should not be conceptualized separate from the building form considerations. Faridani makes similar observations by prescribing a set of unique architectural exercises in his building design-construction series courses where students experience the architectural and structural characteristics of various forms while they also build them by hand. These types of exercises familiarize students with the inherent architectural and structural engineering qualities and geometries inspired by natural forms and forces. Saremi also recognizes the advantage of model building by hand and examines the behavior of different construction materials such as metals and timber while exerting forces on them. Much of an architect’s initial understanding of and exposure to various forces was driven or inspired by the forces of nature (i.e., trees and plants). To Zeineddin too:

*Space and forces acting on it constitute the essence [of architecture]; the building’s structural components are actually devised for controlling and taming those forces. Architects and engineers, hence collaborate to propose and generate innovative architectural forms, because neither architects can generate new forms without a concise understanding of such forces, nor can engineers successfully control them with only columns, beams, and walls alone (in Farsi).*

Kalantari and Hashemnejad raised similar points by emphasizing the stability and unity of architectural forms, and practicality and feasibility during implementation. Diba, Saremi, and Arfaei emphasize the integration of architecture and structure demonstrated in important historic buildings (i.e., the Pyramids at Giza). For Saremi the design process does not begin with a
structural concept, but with the confluence of form, function, volume, stability, structure, and indeed, the ultimate users in mind (Figure 4). In Saremi’s work, walls have a special role to play; they are at times thin and at times thick. Remembering his mentor Louis Kahn and his “French Structural engineering Professor” while studying at the University of Pennsylvania, Saremi considers the wall’s main function as not only organizing the space by providing natural lighting, but also as dealing with the forces of gravity.

Zodiac 22 Light Structures illustrates one way of thinking about integration rather than competition between architecture and structure. This old publication contains many geometrical possibilities whereby structure, architecture, and mechanical installations can be cohesively and congruently integrated. The majority of Faridani’s examples and his students’ projects exemplified the expansion of geometrical forms.

Content
All interviewees express similar ideas regarding the content and substance of what architects should know. While they believe architects should acquire a standard set of artistic as well as technical/engineering skills for designing buildings, they question the extent and sources of these skill sets. There was consensus regarding the architects’ representation capabilities from free-hand drawing to computer simulation and visualization skills. They were less unanimous however, in terms of the sources of these knowledge types. For example, while some stress the importance of canonical or expert knowledge, others like Arfaei, Kalantari, and Hashemnejad emphasize local knowledge as a more powerful source of inspiration instead (Figures 5, 6, and 7). The discrepancy between the expert and local knowledge reflects a larger gap in the architectural pedagogy where the former reflects the supremacy of authority in architecture the latter celebrates common sense, intuition, and good judgment not so much as a by-product of technical competency but as a virtue which evolves over time commensurate with experience.
Figure 5: Local knowledge informs Arfaie's architecture (Source: Authors).

Figure 6: Residential Building, Tehran, Iran. Kalantari utilizes structure, architecture, and the choice of building materials from early stages of design (Source: Authors).
Various themes including problem-solving, observation, intuition, self-discovery, and professional experience capture the type of knowledge the interviewees stress in architecture. They also emphasized free-hand sketches in expressing and illustrating design concepts (Edwards, 2005; Prats, et. al., 2009). While the interviewees understand the significance of hand-eye coordination and simple free hand sketches, they discourage the use of computer at the early stages of design thinking.

Other related issues associated with the use of free hand drawing include simplicity, naturalism, simulation, and practicality. For example, Hariri’s sketches of a building he designed almost thirty years ago illustrates how he incorporates structural thinking (showing a customized steel hinged joint for a column to foundation in a house laid out on poor soil) into other concepts such as sustainability and practicality, and even the use of quick hand-drawn details of a wall-section. A systematic use of geometry in creative architectural thinking is another skill, which Faridani considers critical in developing the hand to eye coordination and appreciating scale in good design. On the other hand, like Charleson and Pirie (2009), Zeineddin urges engineers to understand good architecture so as to recognize their role not solely as experts who can perform complex calculations, but as facilitators who collaborate with architects in the problem solving process.

Diba underscores another important skill for architects. The adage “practice makes perfect” captures Diba’s conviction regarding the importance of professional experience in architectural training. By using Indiana Jones as an ideal example of an archeologist who practices archeology most of the time, but teaches only a few hours a week, he articulates the utility of this model in architectural training as well. Diba rejects the current practice of architectural mentors who spend most of their time in the classroom and on campus rather than gaining outside experience. Furthermore, he emphasizes self-discovery and observation rather than solely relying on textbooks and abstract theoretical knowledge, which usually become obsolete if they do not stand the test of time or in practice. His call for incorporating practice or
field-based knowledge echoes Watson’s notion of “technology as tacit knowledge,” whereby technology alone is defined by three components: structures, construction, and environmental control” (Watson, 1997: 125). In his call for integrating technology and design, Watson argues:

> if design and technology issues are not integrated, architectural students never really experience how the design idea, the line drawn on paper, can be informed by technical knowledge—the analysis of structure and construction or the quality and quantities of sunlight—that is, certainly not until after the design is formalized (Watson, 1997p. 125).

The majority of interviewees pointed out the virtues of “seeing” as the type of skill architects must develop in their training. These remarks are similar to Schon’s virtues of “seeing” and “reflection” in designing (Schon and Wiggins, 1992). To better illustrate this skill, one interviewee reminds us of the principle of maximum efficiency with minimum materials in a bird’s egg. The main function of an egg’s shell, which is protecting the embryo with the minimum material, is done naturally and masterfully (Taghizadeh, 2006). Using more materials, however, could not only make the egg more brittle and heavier, but also jeopardize the mother’s overall health. As such, a bird’s egg represents a three-dimensional natural model in which the compression forces are evenly distributed across a thin shell.

This three-dimensional curved form becomes the main premise for designing domes and thin shell structures. Domes exemplify the integration of architectural and structural logics in adopting efficient and relevant natural building forms. Domes naturally distribute the lateral and gravity forces to the load bearing structural elements. However, the misuse and misunderstanding of this simple logic can result in the proliferation of flawed and inefficient structural systems in mosques for example. In many contemporary mosques, the use of horizontal steel beams at the base of the dome causes many problems. The shell naturally transfers the forces acting on the dome, and makes the use of horizontal beams redundant and unnecessary. This situation clearly increases the vulnerability of the dome because the transfer of forces to horizontal structural elements makes the shell thinner, and consequently increases the likelihood of creating cracks and leakage on the dome’s concrete surface. This whole scenario clearly demonstrates the designers’ lack of understanding and appreciation of natural forms, which leads to many structural and aesthetic problems.

CONCLUSION
This article has critically explored the utility of structural engineering concepts in architectural design thinking. By conducting in-depth interviews, twelve renowned Iranian architects/educators shared their insights about the utility of structural engineering concepts in architectural design. The interviews focused on the nature, outcome and content of the relationship between architecture and structural engineering. They used metaphors (nature, fetus, and organism) to describe the nature of this relationship while advising against abstract structural calculations, and instead, calling for integration rather than competition between the two fields in design thinking. Finally, by criticizing the existing chasm in the current architectural education, they emphasized intuition, common sense, self-discovery, and observation as part of the necessary knowledge base for architects.

Using formulaic structural calculations detached from their architectural expressions are widely practiced in the architectural education in Iran as well as some other parts of the Middle East. However, adherence to rigid engineering principles invokes mixed feelings in pursuing self-discovery and intuition, which according to the majority of the interviewees, students of architecture need to explore. This preferred integrative model of design thinking is neither institutionalized in Iran nor the Middle East. Encouraging students to pursue such approaches to architectural design as opposed to making sharp distinctions between architecture and structure represents the thrust of the interviewees’ comments.
The irony is that while structural engineering concepts are perceived to be precise, rational, rigid, and less open to idiosyncrasies, architectural design thinking is rather subjective, artistic, and more personal. Filling this rather wide gap between the sheer logic of structural systems vs. the subjective nature of architectural design remains to be a major challenge in architectural education—especially among the proponents of each camp. The common wisdom among the structural engineers still seems to revolve around strict adherence to engineering principles while architectural educators opt to de-emphasize these courses and favor replacing them with courses, which invoke intuition and self-discovery in students.

REFERENCES


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