Journal of Civil Engineering and Architecture 19 (2025) 607-619
doi: 10.17265/1934-7359/2025.12.005

The Graphics Instruction Methods Are Quite Instrumental

Browne, Mazzuca
Kennesaw State University, United States

Abstract: This paper discusses the integration of graphic learning strategies and motivational issues for undergraduate architecture students learning of basic and introductory structures. Rethinking the topic's instructional design addresses the need for improved appeal, relevance, and engagement in the technical course, integrating graphic methods (precisely scaled drawing) in the scaffolded learning of complex tasks, and summary application in a problem-based final design project. Students are tasked to manually employ scaled drawing skills to represent the attributes of forces: magnitude, orientation, and action lines. These are indispensable in establishing graphic proofs to construct cognitive linkages to the accompanying computations accurately. Precisely drawing a multi-force loop leads to a math literacy where equations are not disconnected cognitively, but are generated consequentially from the graphics. This complex skill allows a better learning of truss design and through the use of layered force-loops, aka Maxwell's diagram. The problem-based final design project is initiated through analyses of selected case studies, constructing links between the graphic learning methods of structures exercises to recognized, built projects by well-known designers. Most importantly, through discussion, the case studies serve as learning bridges between the technical procedures in basic structures to the design and refinement of the projects' formal shapes. The final project (a spanning structure, such as a bridge) is then design and analyzed by student teams, applying the learned skills in a critical-thinking setting. The graphics instruction methods are quite instrumental in the guided learning of complex tasks while the problem-based approach helps in motivating the students' critical learning of structures, encouraging a deeper appreciation between form and forces. Pedagogically, while these instructional methods show some marginal improvements in learning performance, initial student responses point to better attitudes towards the subject matter. Further studies are recommended to verify the merit of the instructional strategies, and desired knowledge transfers to the design studio.

Keywords: Architecture education, structures, graphics, learning strategies

1. Introduction – A Teaching-learning Mismatch

Architecture students are predominantly visual learners (Mostafa and Mostafa, 2010). Evidence of their visual style as a preference of multiple intelligence modes (Gardner, 1993) comes in the form of sketches, studies, final detailed drawings and models, designed and generated in the design studio. Additionally, undergraduate programs have different course series that define the architecture education experience. The first course of the required series on structures serves to educate architecture students on the fundamental topics of forces, equilibrium, stress, and other statics/mechanics topics. These structures courses have, for most part, been delivered with lectures and computations, based on the engineering class as an instructional model. While students acknowledge the significance of structures in their design education, they also show signs of disconnection with the conventional lecture format employed in these classes. Observations reveal average performance, low motivation, and uninspired engagement. Students struggle with the logical reasoning that generate the algebraic equations. This relative level of numerical illiteracy sets up a difficult learning experience, leading to disenchantment and non-positive attitudes towards learning. The class does not resound "architecturally" due to 1) the weak appeal of the analytically focused math, 2) the lack of relevance linking detailed structural lessons to larger

Corresponding author: Browne, Mazzuca, Ph.D., research field: architecture.

issues in designing architecture; these contribute to poor confidence and low satisfaction in the motivation to learn (Keller and Deimann, 2012). Clearly there is a teaching-learning mismatch. A conflict exists between the conventional lecture/computations instruction and the architecture students' visual learning mindsets. As a faculty member who values both architectural design and structural thinking, I ask: "What instructional perspectives can be considered and practiced to bridge the learning gap?"

2. Considerations for Teaching and Learning

2.1 Improving Math Instruction with Graphics

Math instruction has been evolving to address the issue of low appeal and poor engagement. To sample a few recent studies : Savitz, Brown-Savitz, and Savitz (2012) write of alternative approaches based on multiple intelligence theory. The use of well-designed visuals with narrative delivery responds to cognitive load issues and improves engagement and learning, particularly for visual learners (Strauss, Corrigan, and Hofacker, 2011). Lin and Atkinson (2011) support the use of graphic cues and multimedia in the instruction of scientific concepts and processes; in short, the right kind of graphics delivered properly with instruction is more effective than instruction without them (Diezmann, Lowrie, Sugars, and Logan, 2009). The usage of precise graphics in instruction and learning can lead students to "knowing" how structures behave, and directing the algebraic equations from the drawings themselves. Graphics serve to bridge the learning gaps; simultaneously, the architectural language of drawings and diagrams helps to transform the prescriptive engineering math class into an interactive architectural course.

2.2 Additional Learning Considerations

Integrating graphics as a communicative medium in teaching and learning is deliberately selected to aid in the scaffolded instruction of complex learning tasks (Merriënboer, Kirschner, and Kester, 2003). Learning in a social setting with mentors and peers encourages active collaborative learning (Nicol and Boyle, 2003; Slavin, 2014); crisp discussion amongst peers clarifies and deepens learning (Budesheim and Lundquist, 2000; Vo and Morris, 2006). These considerations alter the learning environment beneficially for novice learners, expanding communication paths of information from unidirectional (teacher → student) to lateral (teacher ↔ teams ↔ student peers). Because the structures topics are introduced at a foundational level, instruction and learning techniques are intentionally conducted in manual mode. James and Engelhardt (2012) point to the role of manual learning of writing skills in the construction of linkages between different parts of the brain. Furthermore, Mueller and Oppenheimer (2014) report on how student performance was weaker when notes were taken by laptop, instead of being constructed manually. Similarly, these papers support the strategy of learning the introductory structures more critically through manual learning modes. Finally, organizing the learning activities in a deliberately guided sequence and framing it against the backdrop of larger architectural questions give a more reliable structure to the learning (Kirschner, Sweller, and Clark, 2006), and a deeper level of relevance and significance to the content. The critical thinking developed in this course through the critical and contextual shifting of perspectives (Black and Duff, 1994) aligns with the cultivation of mindful learning (Langer, 1997), while associations developed from these multiperspectives help to establish better retention and operation of the knowledge in long-term and working memory (Dirksen, 2012).

3. Precise Drawing - from Forces to Trusses

3.1 Drawing Forces and Loops

Learners in the structures course are sophomore students or older. By this time, they are relatively well trained in scaled and precise drawing. By visually depicting every force vector with a length (scaled magnitude), an angular direction (orientation), and a location (line of action), the student makes evident whether each force has positive (↑,→) or negative (↓,←) components to it (later on, with forces acting on joints, these attributes of force help to determine whether they are compressive or tensile).

The first learning hurdle is for students to believe that their precise drawing ability can play a key role in constructing their math comprehension. Initial resistance to this learning concept happens, although staying with this technique through the first force addition exercises promptly establishes positive proofs to surmount the belief-obstacle and support the method. The transformation occurs when the practice of solving first then drawing poorly changes to precise drawings that cue the force numbers into place.

As the exercises in force addition progress, two key points evolve. First, forces drawn in a loop begin from a starting "zero" point and follow a oneway flow (tail-head, to tail-head, etc.) for all known force vectors. Secondly, equilibrium is defined as a total sum of zero; graphically speaking, a force system with a total of zero will translate as a force loop with the equilibrants returning "home" to the starting point, a very clear and confirmative visual that learners may rely upon (Allen & Zalewski, 1998). This practice prepares students for the next topic of analyzing and understanding trusses.

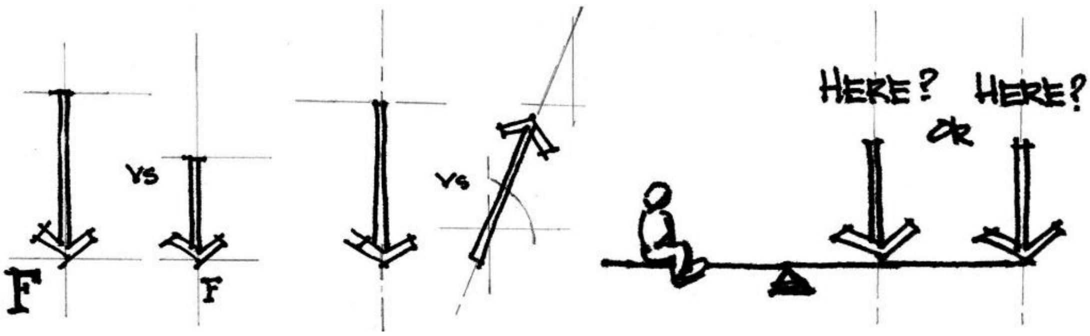

Fig. 1 The sketches below show the significance of the three force attributes of magnitude (left), orientation (middle), and line of action (right).

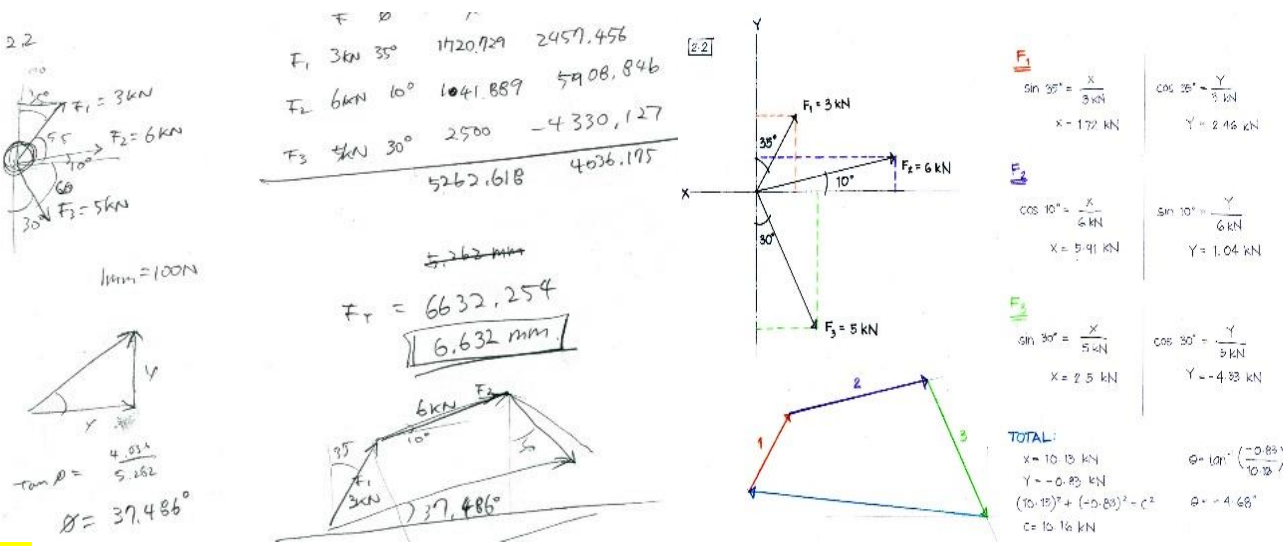

Fig. 2 Force addition exercises. Initial resistance (left) is usually seen with calculations first (often with mistakes) and a sketchy drawing afterwards. In contrast, drawing the loop of forces precisely first (right) leads to more accurate visual cueing of force components.

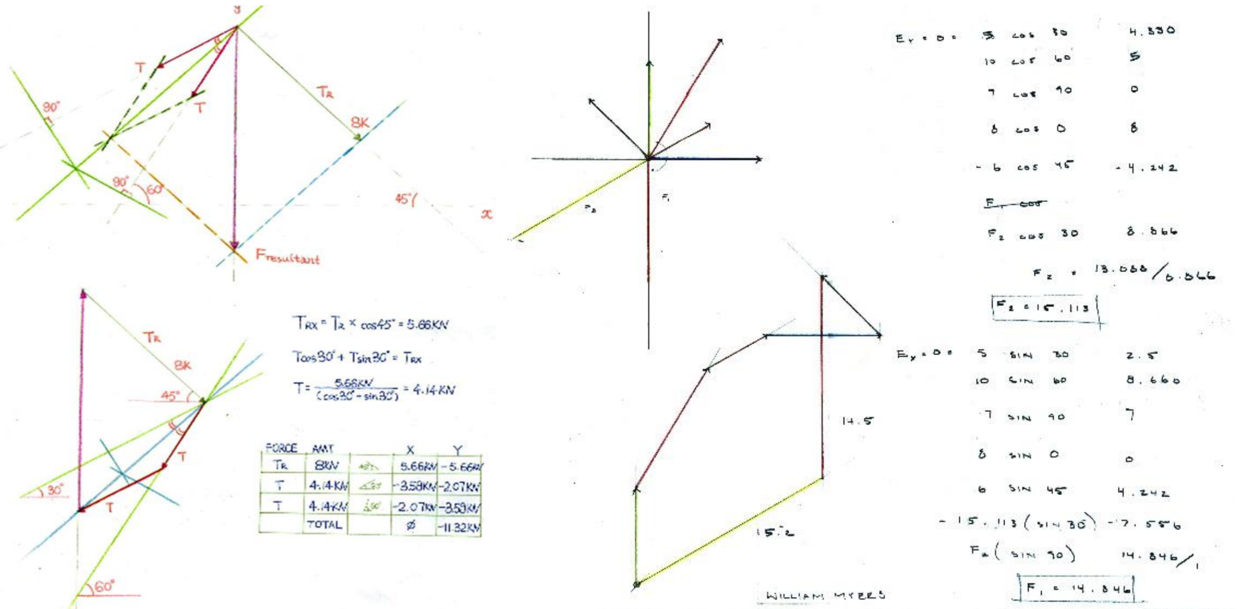

Fig. 3 Force addition exercises. Below are two further examples of student work showing how precise drawings can pave the way for direct enumeration and computation of force components accurately, closing the force loop into perfect equilibrium. For visual learners, the use of colors also helps to organize the process, force by force.

3.2 Understanding Trusses

Precision drawing of equilibrium force loops, once mastered, is applied as the appropriate tool for the topic of trusses, or more specifically, the analysis of forces within truss members. Before analysis can begin, external loads are balanced with reactions, achieving external equilibrium. The conventional approach is known as the method of joints. Architecture students struggle when applying this computation-prominent method, primarily due to the absence of instructive graphic cues, and the cognitive overload of generating equations while tracking force orientations. Errors with one joint will logically affect succeeding joints; and troubleshooting for the embedded errors becomes a frustrating challenge. The Maxwell diagram addresses these issues by being a precision graphic analysis method that draws forces to scale, while simultaneously tracking their force orientations. Rooted in the force loop, this approach reduces cognitive load, clarifies the calculations, and relieves anxiety in architecture novice learners.

In learning the Maxwell diagram, particular guidelines include solving a joint with no more than two unknown bars, remembering to counter-face force arrowheads at the ends of each truss bar, and color-coding forces that push into a joint as compressive (blue), and forces that pull away as tensile (red). These are in addition to the clockwise-loop reading of forces in a joint and the practice of precise and consistent scaling when drawing forces. The Maxwell diagram does not detract from the math discipline required in the method of joints. In fact, by drawing an equilibrium force loop for each joint analyzed, the complex truss is broken down into multiple force-addition exercises, each one simpler to execute and compute with the visual cues offered by the accompanying force loop.

Appreciation and mastery of the topic are better achieved through exercise variants. Because the force loop and the Maxwell diagram serve to construct math comprehension in architecture students more clearly and efficiently, series of measured variations are able to inform the students of relationships between truss designs and internal forces. These allow for informative discussions on optimizing overall form, diagonal layouts, material choices, and even expressive potential.

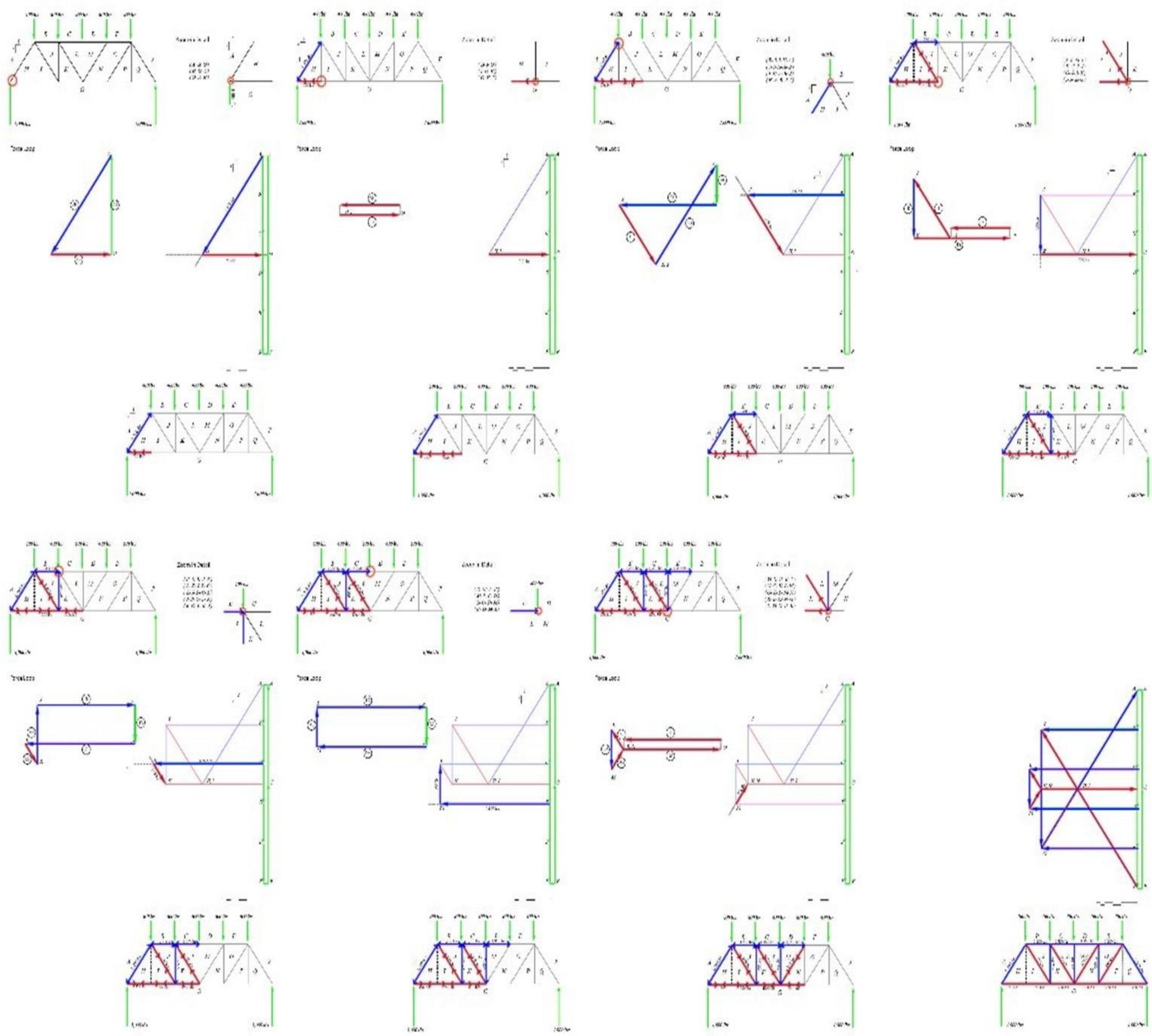

Fig. 4 The Maxwell diagram in eight panels. Below is a sample truss with symmetric form, loads, and reactions. The analysis begins with the determinate joint (top left). With every succeeding joint, nested force loops grow into the cumulative Maxwell diagram, and internal bar forces are colored-labeled onto the truss itself. Upon reaching the midspan, the truss forces and Maxwell force loops are mirrored, completing the truss analysis with the identification of both compressive (blue) and tensile (red) forces.

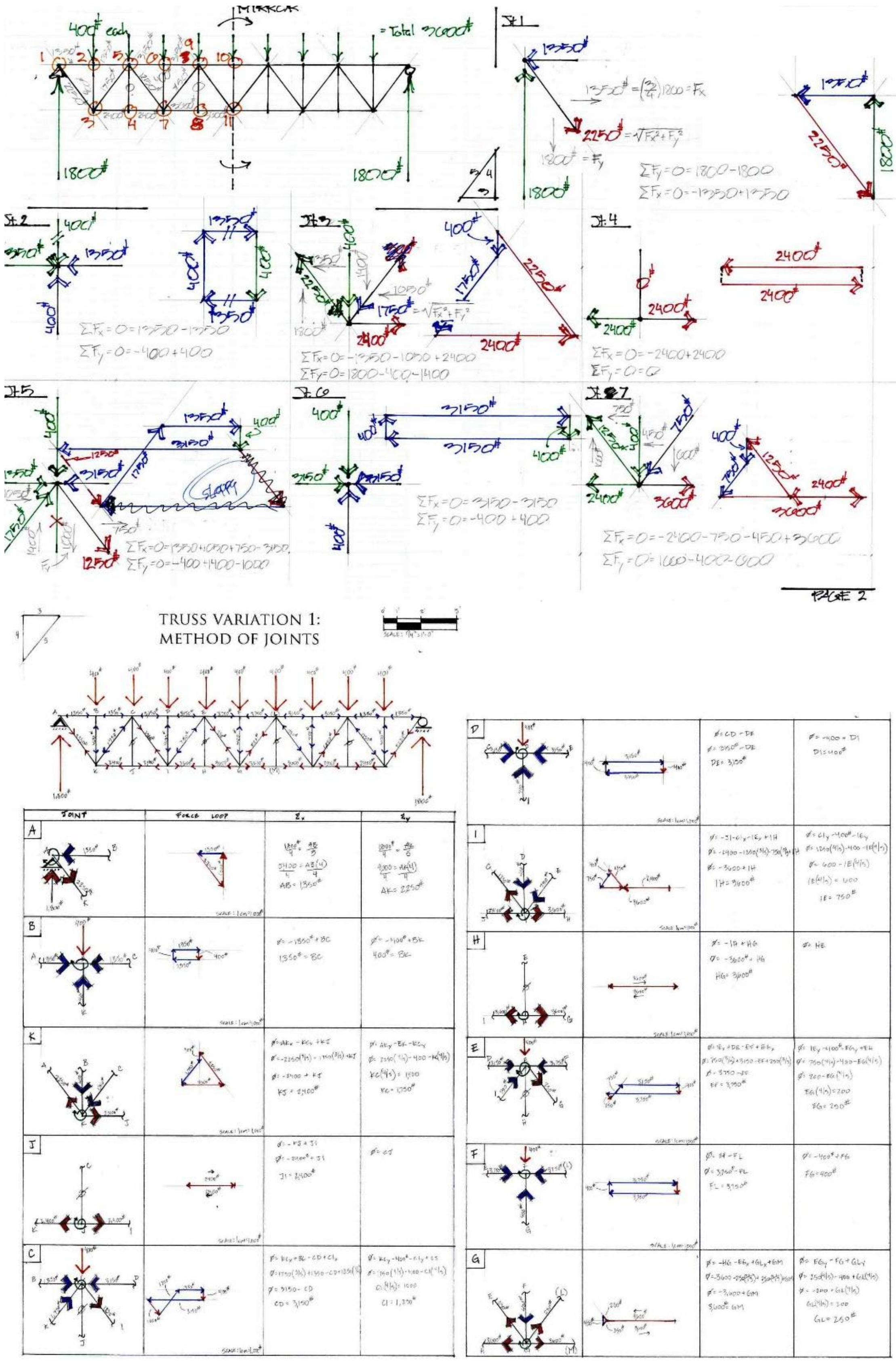

Fig. 5 Sample student works. Taken one joint at a time, the corresponding force loop helps to generate the force equations and keep track of force orientations when moving onto the next joint to be analyzed.

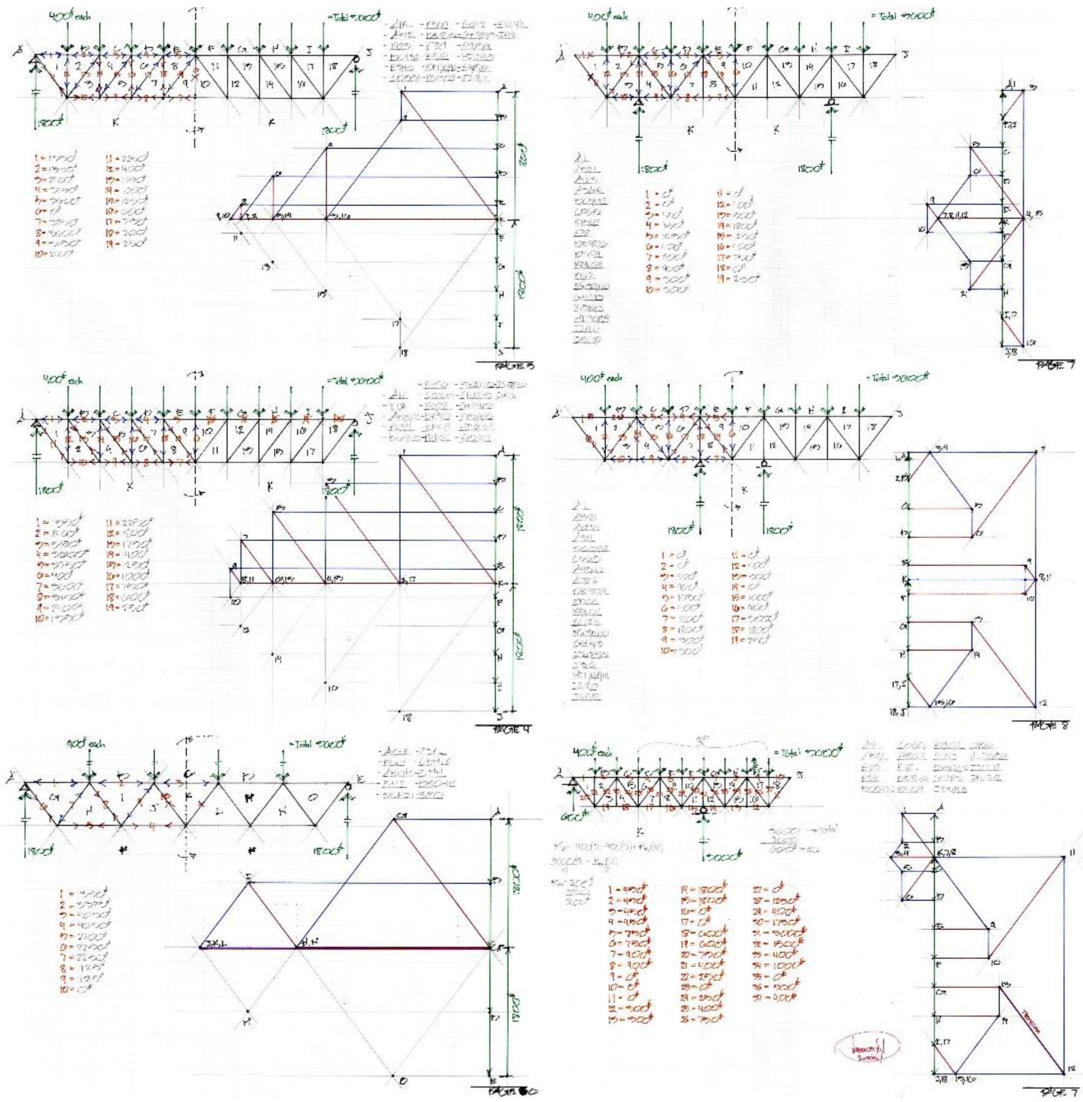

Fig. 6 Sample student works. Truss variations help to inform learners of relationships between form and forces. Left column shows diagonal layout variations; right column depicts variations of reaction locations.

As with all things to be learned, practice makes perfect, and there are no short cuts to mastery. These deliberate use of precise graphic skills in instructional strategies discussed in this paper do require a level of commitment and craft from the architecture students, a culture best nurtured through modeling by the instructor, in coordination with the student team leaders. Along with the deeper comprehension of the content and relative mastery of the skills, these visual learners are better positioned to experience increased confidence and satisfaction for work done competently. And with increased confidence and satisfaction, the level of interest and engagement with content also increases.

4. Addressing Relevance – Case Studies and Context

"Why am I learning this?", and "How is this architectural?" are the questions that linger in students' minds, even if they acknowledge that structural issues are of importance to design. This need to link the course topics to the larger learning goals of architecture students is an issue of contextual relevance that affects motivation and deserves proper engagement. The learning activity that addresses this need has the objectives of establishing visual and cognitive linkages between their exercises and recognized works of architecture. This is a key task that improves mindful learning through shifts of perspectives and context (Langer, 1997; Black and Duff, 1994).

By calling on student teams to comparatively analyze and critique selected built projects, the learners have the opportunity to construct cognitive associations between their exercises and the case studies' structural forms and behaviors; similar to the precedent studies they conduct in design studio, the learners are able to grasp more clearly how particular projects physically support themselves and how such structural choices contribute to the generation and expression of form and detail.

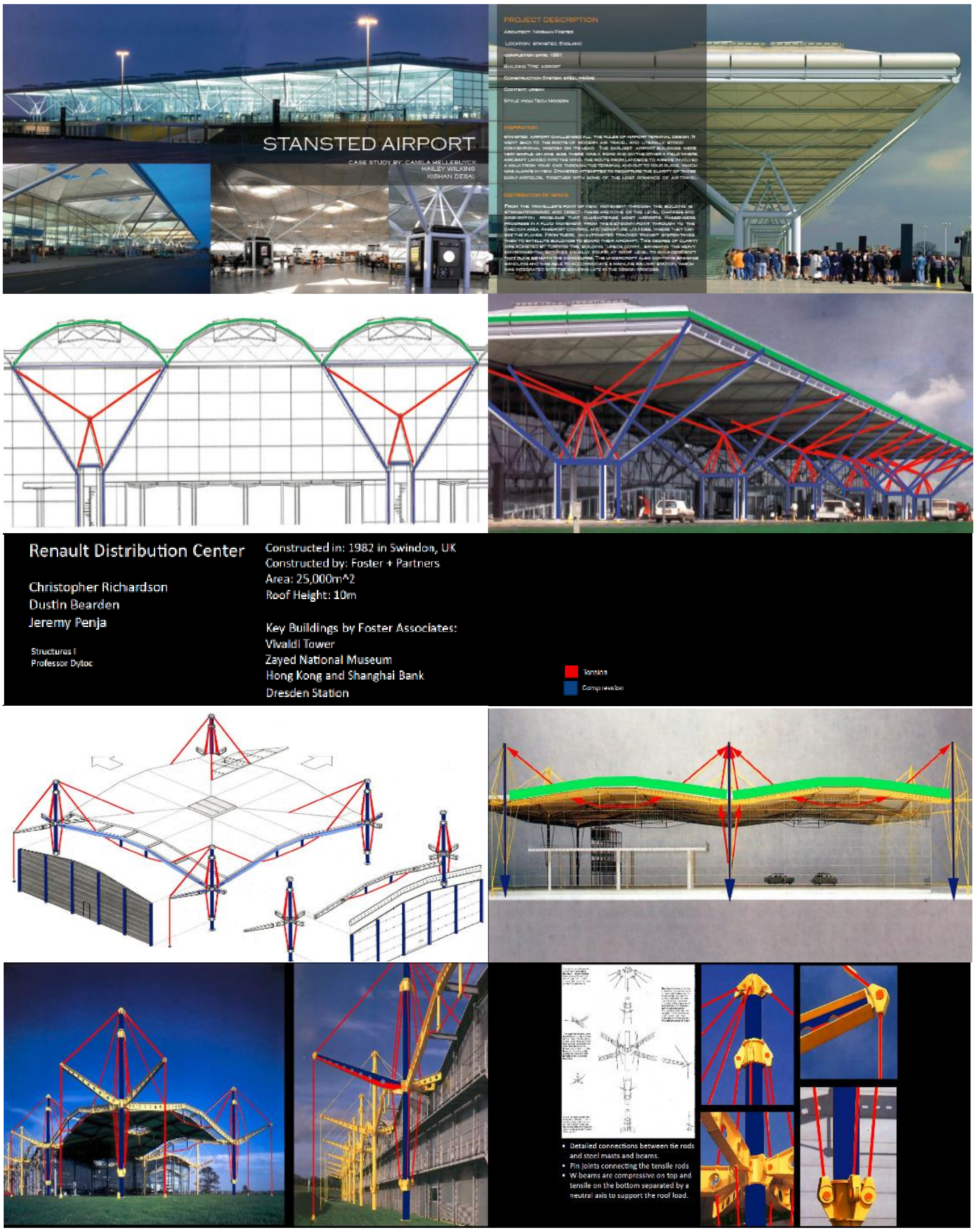

Fig. 7 Students analyze selected built projects, recognized as noteworthy designs. The structural system is investigated and elements are coded in color to identify their structural roles, establishing linkages between structural form, behavior, and expression.

5. Closing the Gap – Applying the Skills Into Design

All of these instructional approaches have evolved (and are still evolving!) to address learning performance, engagement, and motivation. These are considered to construct cognitive ties to and improve their growth in design. The sequence of employing precise drawing methods and case study analyses leads to and ends with a final application project : designing a structural solution to a fuzzily defined problem, often a spanning requirement (a bus stop, a parking shed module, a pedestrian bridge, a cover for an atrium, e.g.).

Taking cues from the critiqued case study presentations and the team-based scaffolded learning of their complex-task exercises, the architecture students now are able to better understand the relationships between forces, stresses, optimal performance, and the potential aesthetic clarity. The task of the final application

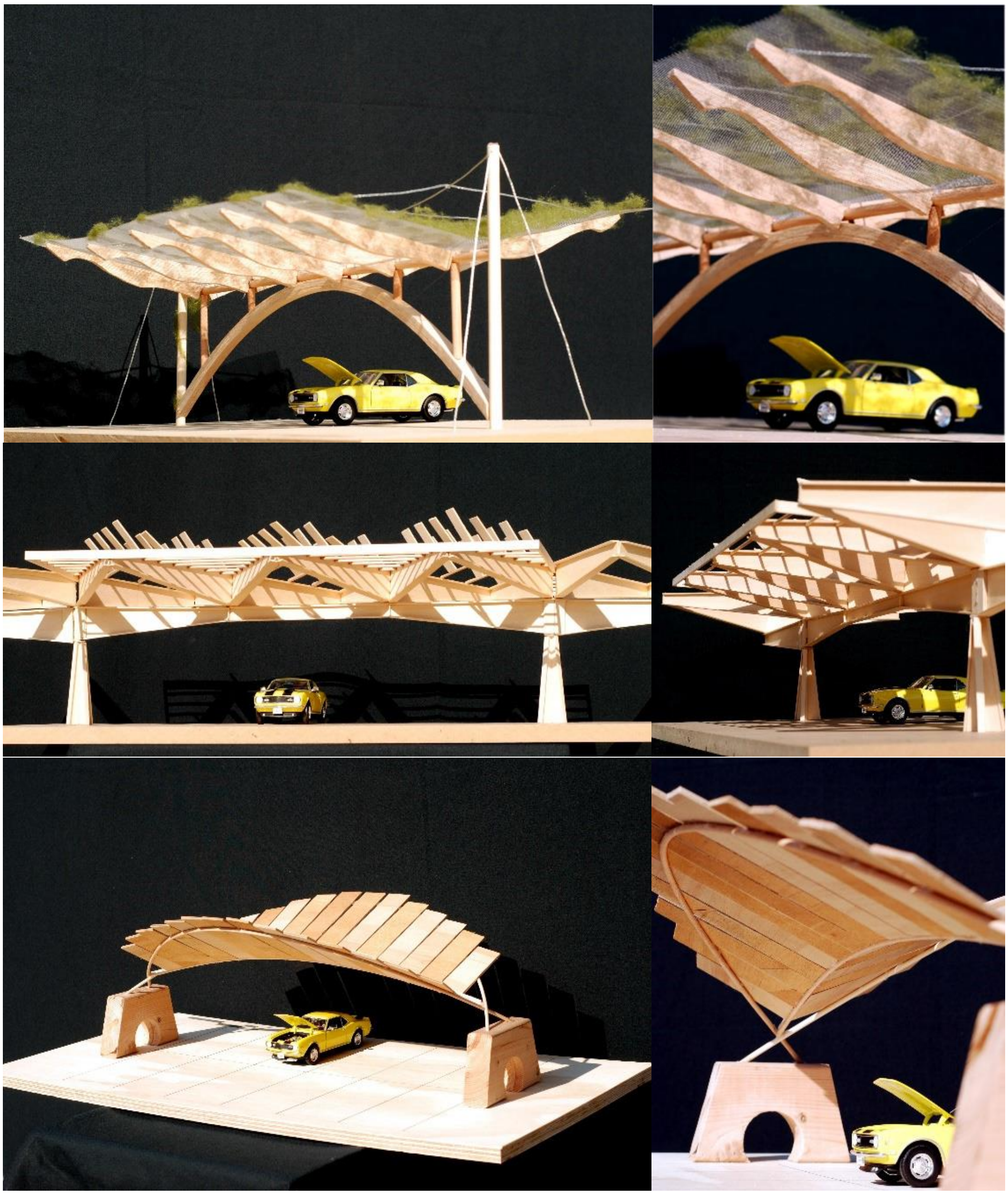

Fig. 8 Design projects by students. Three parking roof structures.

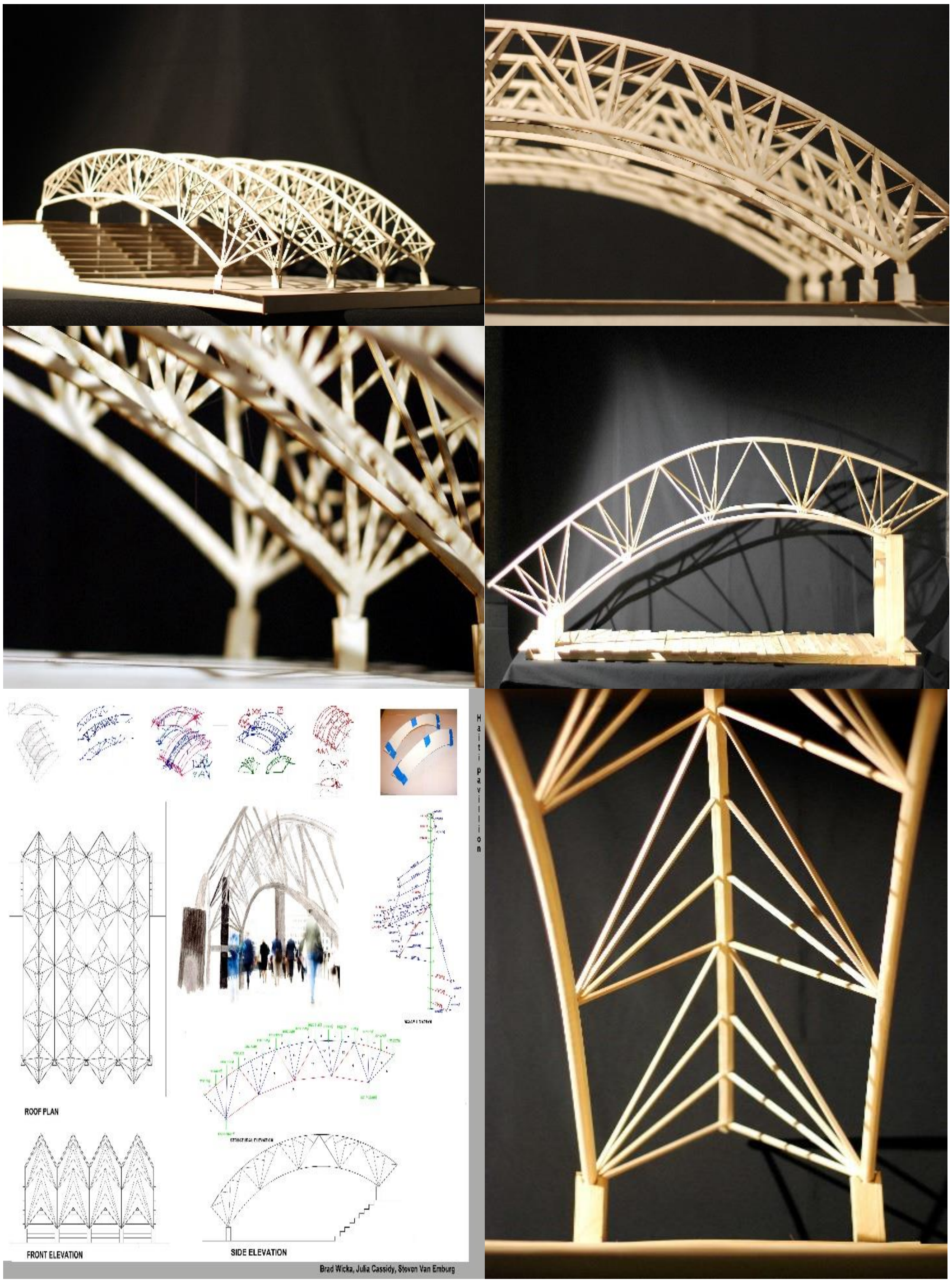

Fig. 9 Design projects by students. Community hall structure. The student team designed a module of a curved, folded-plate truss, repeating over 4 bays. Anticipating more compressive stresses on the top chord, and more tension along the bottom chord, diagonals were laid out to have more joints along the top, resulting in shorter length top-chord bars and longer length bottom-chord tension rods. Graphic analyses at bottom left.

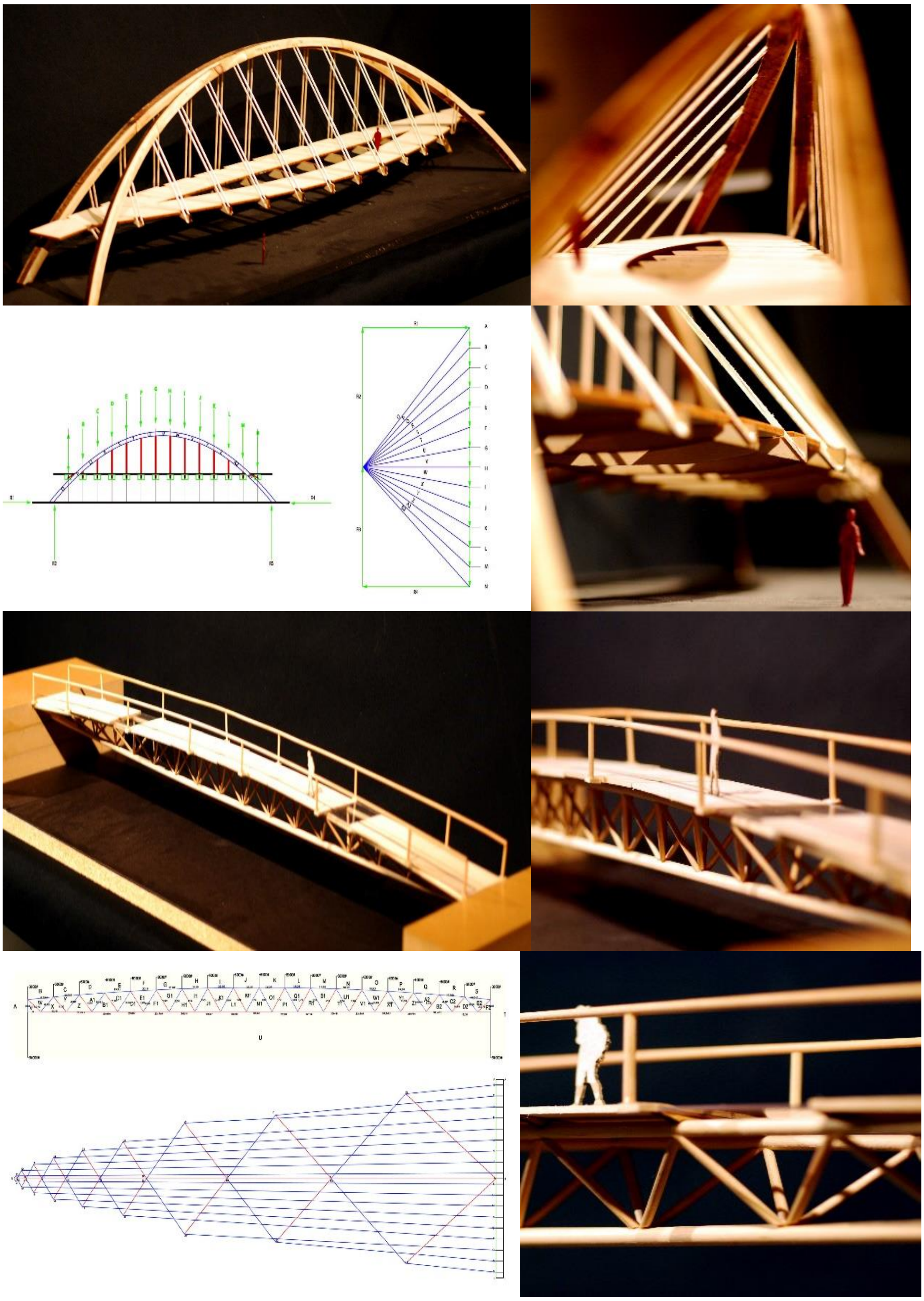

Fig. 10 Design projects by students. Pedestrian bridges. The top bridge design has a split deck and canted-arch pair as its main structural scheme, partly inspired by Calatrava's bridge at Bach de Roda. The bridge design below elects to have a more slender shaped prismatic truss below deck with a pronounced tension line, partly inspired by the Waterloo International Terminal by Grimshaw. Analyses graphics at bottom left, each.

project carries both performance as well as formal objectives. On one hand, the design proposals that the student teams develop must have structural clarity; loads are derived and the structure is graphically and numerically analyzed, engaging the knowledge and skills they have acquired through their several exercises and collaborative learning structure. Furthermore, their design must be built as a model and documented or simulated from several pedestrian points of view, resulting in photographic proofs to capture the less tangible yet experientially valid qualities of their design proposals.

6. Reflections and Recommendations

The integration of precise graphics in the instruction did not replace required computations; it can be argued that this teaching and learning strategy resulted in presenting more information than the traditional lecturecomputation class. However, I would instead respond that the conventional teaching structure presented to architecture students contained cognitive and learning gaps. These gaps did not increase the quantitative literacy of these visual learners, nor their motivation to learn the content. Based on observations of student behavior with these instructional strategies, I did see improved attitudes and active engagement with their teams and peers. The class atmosphere was notably more active and positive; and the resence of rapport between students and instructor indicated a stronger level of motivation for the learning. The assignments also exhibited better math comprehension, and the drawing discipline upgraded the craft in their works. The students expressed more satisfaction, despite the knowledge that they had to invest more effort and focus. Student opinions agreed that the graphic methods in the instruction led to better clarity of the content and comprehension of the math. Their remarks also showed that interaction with peers enhanced their learning. Similarly, they indicated higher motivation. Feedback reaffirmed the engineering nature of the class, the analytical character of the content, and the relevance of the course. Additionally, they also felt that the deliberately different approach to learning made the class atmosphere creative, interesting, and, quite importantly, architectural.

Reflecting on these instructional practices, I realize yet again that they are all rooted in the learner-centered view of education. As a concerned educator, I must remind myself that it is crucial to induce an active desire for learning in the student. I believe completeness and clarity of communication is a prime goal of teaching, so that the students themselves may be capable of passing their learning forward with the same level of completeness and clarity. I write this reflection with the awareness that other educators from other fields may be considering if the instructional strategies described here may be of interest to their own teaching. I would then state that the precise graphic instruction methods, along with other instructional tactics, were purposefully developed to fit the visual learning profile of the architecture student, in response to particular teaching-learning gaps. I would therefore recommend that these different aspects be contemplated on as one develops a thoughtful instructional program. It is possible that the specific practices employed with this class may offer similar benefits when applied or adapted to similar courses. Subsequent research may be conducted to better evaluate the merits of these instructional strategies, especially with visual learners. Research may also investigate whether these methods may be effectively transferred to other technology courses in architecture.

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