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The Kind of Problem Technology Is: A Case for Integrated Models of Architectural Technologies Education

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Organized Complexity

In *The Death and Life of Great American Cities*, Jane Jacobs writes “the theorists of conventional modern city planning have consistently mistaken cities as problems of simplicity and of disorganized complexity”. In the final chapter, “The kind of problem a city Is” she follows with, “why have cities not been identified, understood and treated as problems of organized complexity?”¹ Inspired by Jacobs’ call, the authors of this paper, seeking to reinvent technology courses for undergraduate architecture students, ask “why has architectural technology not been identified, understood, and treated as a problem of organized complexity?”

The guiding principle for a redesign of second-year technology courses derives from the definition of organized complexity as understood by Jacobs. Distinct from problems of *simplicity*, which are characterized by having two variables with clear relationships to each other, and from problems of *disorganized complexity*, which might include millions of variables whose behavior is best determined probabilistically through the use of statistical analysis, problems of *organized complexity* require the coordination of a sizable number of variables that are interrelated into an organic whole.² In other

words, to discuss daylighting strategies, for instance, independent of an understanding of available solar resources; the qualities of glass through which the light passes; the wood on which the light falls; the reradiated energy that must be mechanically removed; and the environmental impact of this machinery, is to segregate and oversimplify an issue that is best understood within the context of interrelated *contextual*, *material*, and *energy* systems.

Acknowledging the inherent complexity of architectural technologies and the interrelated nature of the distinct knowledge areas included within them, the authors have worked to integrate instruction in materials, methods of construction, and environmental controls by distributing multiple short modules of each topic across a 30-week academic-year (*Fig. 1*). Additionally, new course content focused on methods of site analyses has been added to the existing curriculum; acting to contextualize architectural technologies within large-scale environmental systems. The authors have worked together to deliver modules pertaining to their individual areas of expertise. This reinforces the importance of collaboration as modules and instructors loop—supporting one another and building sophistication and specificity over the course of the year.

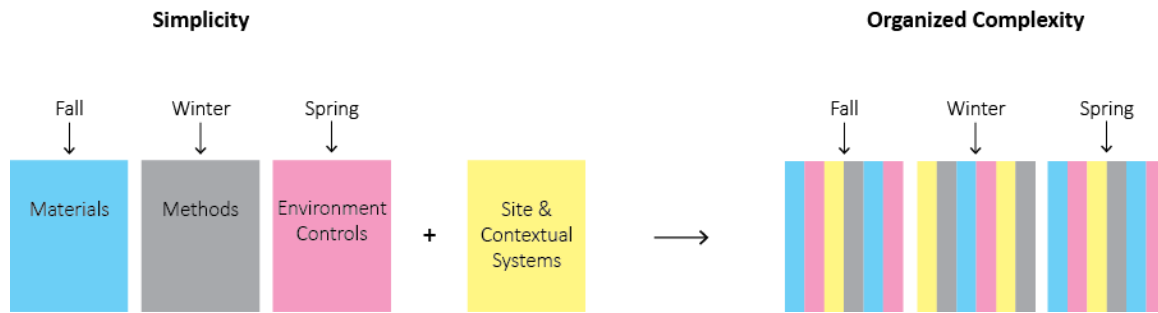


Fig. 1. *Integrated Technologies Course Organization.* On the left shows the previous model where topics were separated by quarter, and site systems was not formally covered. On the right is the new curricular model of integrated topics taught each quarter.

Provoked by a perennial responsibility to align architectural education with evolving contemporary practice, this paper works to establish a theoretical basis for the consideration of architectural technology as a problem of organized complexity. It expands on teaching methodologies developed by the authors and provides a critical reflection on experiences from a 2-year pilot of these courses.

Aligning Course Organization with Contemporary Architectural Practice and Student Development

Shifts toward models of *organized complexity* have begun to appear within the mainstream disciplinary activities of practicing architects. Notably, in November 2016, the National Council of Architectural Registration Boards (NCARB) launched a restructured version of the Architect Registration Examination (ARE) featuring an integrated model of organizing test subject areas (Fig. 2). Since the beginning of its national standardized testing in 1965, the NCARB has performed periodic monitoring of the discipline in order to assure the maintained relevance of the ARE to the daily practice of architecture.³ Beginning with the *Task Analysis and Validation Study* in 1979, and more recently through the *Practice Analyses* published in 2001, 2007, and 2012, the NCARB has regularly adjusted its testing format, introduced relevant workflow technologies such as Computer-aided Drafting, and updated the content covered in the ARE.⁴ Given its

analytical bases, it could be argued that the ARE offers a representation, albeit conservative, of trending disciplinary concerns over time; in which the most recent iteration signifies a formal acknowledgement of the complex and interrelated nature of the various knowledge areas required of the Architect. Compared to previous iterations of the exam, which, up to now have been organized “vertically” around discrete content areas, i.e., *Structural Systems*, *Building Systems*, etc., ARE 5.0 includes 6 divisions arranged “horizontally” around the progression of a typical architectural project, i.e., *Project Planning and Design*, *Programming and Analysis*, etc.⁵ This flattened model distributes individual subjects across multiple tests and results in two critical distinctions from previous exams. First, organizing tests by project phase rather than subject encourages the integration of multiple knowledge areas within each exam allowing subjects to be paired in relevant combinations. For instance, the *Programming and Analysis* exam might require candidates to assess the probable bearing capacity of soil substrates, determine the allowable floor-area, and identify suitable construction types for a given site and program. This combination melds considerations of material properties with those of building assemblies and zoning regulations in a way that is relevant to the early phases of building design. This organization also allows that levels of sophistication and specificity in each

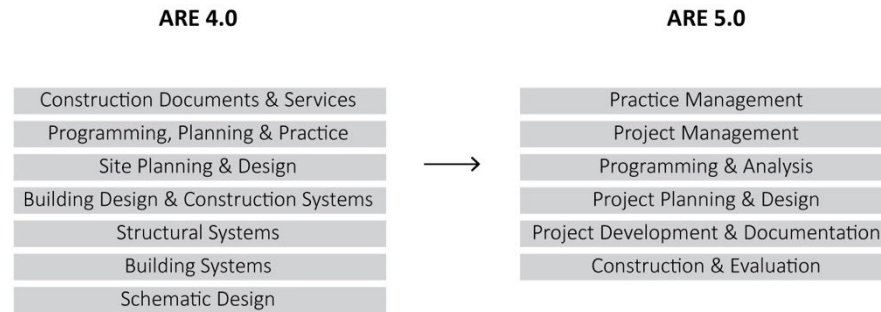


Fig. 2. Architect Registration Exam 5.0 Restructuring, 2016.

knowledge area, as well as in the relationships between them, graduate over the 6 exam divisions, as they are likely to do through the various phases of design development for an architectural project.

Similarly, and returning to pedagogy, integrating architectural technologies education allows content in each subject area to increase in sophistication and specificity across the curriculum and as student knowledge and skill levels mature. A common problem associated with traditional technology course organizations has been determining *when* to introduce any given subject. Given a range of preferences and curricular determinants, it might be ideal to introduce concepts of materials and methods of construction, for instance, early on in a design education. However, this would inevitably come at the expense of withholding instruction on solar geometry and or principles of passive thermal control until later in the curriculum. Subsequently, the depth to which any subject can be explored has inevitably been linked directly to the term in which it is taught—limiting discussions about materials, for example, to the maturity of a first-term second-year student. Alternatively, returning to topics in shorter modules that are distributed throughout an academic year allows those discussions to deepen along-side student development. An intended outcome of the integrated technologies organization is the decoupling of knowledge areas from specific student maturity levels

and the making available of a wider range of technologies to students as potential drivers for design decisions in all of their work.

Curricular Development

The Architectural Technology curriculum at California Polytechnic State University, San Luis Obispo has historically included six courses under the titles of *Practice* and *Environmental Control Systems* and have been taught in the second and third years of the undergraduate architecture program. Within each of the six courses, topics are introduced within (2) 50-minute *Lecture* experiences, serving 120-180 students, while (2) 110-minute *Activity* sections, serving 16-20 students and taught by additional faculty, allow the application of those topics, often to projects underway in co-requisite design studios. Historically, instructors of each *Activity* section have been responsible for developing class exercises and assessment tactics on an individual basis for their respective sections. While this structure has afforded the *Activity* instructors a great deal of flexibility to integrate technology topics within the applied design studio project, it has also resulted in difficulties linking the learning experiences between Lecture and Activity modes and in establishing and meeting a shared set of course learning objectives for the technology curriculum. In response to the ideas introduced above, the authors have initiated a fundamental shift in how Architectural Technology is

taught. Each year now has a bench of three instructors who work collaboratively toward a common syllabus, outline, learning objectives, and assessment tactics. From the student's perspective, instead of six distinct class experiences beginning anew every 10 weeks, they now have a 2nd year technology set of classes spanning three quarters with a great deal of consistency in content delivery and assessment methods, and a similar 3rd year experience. The new courses have been rebranded as Architectural Technology Fundamentals in 2nd year, and Building Systems Integration in 3rd year, as can be seen in the Bachelor of Architecture Flowchart diagram below (Fig 3).

The past model of teaching Architectural Technology siloed content areas by quarter, such that material systems and assemblies were only minimally discussed in the context of environmental control systems (ECS) and vice versa. In the redesigned courses, topics that would have previously fallen under the umbrella of "materials" or "ECS" have been broken down into smaller modules of content. We have also added new course content that was not previously taught in our curriculum in the area of site and contextual systems. We initially

blended the three content areas fully into an uncategorized flow of topics. After the first term of integrated teaching, student surveys revealed that students found it very confusing to keep the three instructors and the interwoven subjects clear. Therefore, we moved to a modular course structure where each instructor teaches for approximately 3 consecutive weeks, and students complete a correlated laboratory exercise and an exam before moving on to the next subject area. Following surveys indicated an improvement in student satisfaction with this early correction to our delivery strategy.

Further detail on each of the course content areas is provided in the following paragraphs. The sequencing of the modules emerged from collaboration with the co-requisite design studio learning objectives. For example, in fall quarter, all design studios work with a small urban infill site in a local city that students can visit multiple times. The subject matter covered in the Technology course is curated to support the studio investigations at some points in time, while at other times the Technology courses lead the students toward possible design drivers.

1st YEAR			2nd YEAR			3rd YEAR			4th YEAR			5th YEAR		
Fall	Winter	Spring	Fall	Winter	Spring	Fall	Winter	Spring	Fall	Winter	Spring	Fall	Winter	Spring
Design & Visual Com. 1.1 ARCH 131 (4)	Design & Visual Com. 1.2 ARCH 132 (4)	Design & Visual Com. 1.3 ARCH 133 (4)	Architectural Design 2.1 ARCH 251 (5)	Architectural Design 2.2 ARCH 252 (5)	Architectural Design 2.3 ARCH 253 (5)	Architectural Design 3.1 ARCH 351 (5)	Architectural Design 3.2 ARCH 352 (5)	Architectural Design 3.3 ARCH 353 (5)	Architectural Design 4.1 ARCH 451 (5)	Architectural Design 4.2 ARCH 452 (5)	Architectural Design 4.3 ARCH 453 (5)	Senior Architectural Design Project ARCH 481 (5)	Senior Architectural Design Project ARCH 481 (5)	Senior Architectural Design Project ARCH 481 (5)
Survey of Architectural Education & Practice ARCH 101 (1)	Survey of Architectural Education & Practice ARCH 101 (1)	Survey of Architectural Education & Practice ARCH 101 (1)	Architectural Technology Fundamentals 2.1 ARCH 241 (4)	Architectural Technology Fundamentals 2.2 ARCH 242 (4)	Architectural Technology Fundamentals 2.3 ARCH 207 (4)n	Building Systems Integratio 3.1 ARCH 341 (4)n	Building Systems Integratio 3.2 ARCH 307 (4)n	Building Systems Integratio 3.3 ARCH 342 (4)	Topics in Architectural History ARCH 3/420 (4)			Senior Design Thesis ARCH 492 (3)	Issues in Contemporary Professional Practice ARCH 443 (4)	
Introduction to Environmental Design EDES 101 (2)	College Physics I PHYS 121 (4) or General Physics IA (8)	College Physics II PHYS 122 (4) or General Physics IB (8)	History of World Arch: Prehistory to Middle Ages ARCH 217 (4) (C)	History of World Arch: Middle Ages to 18th C. ARCH 218 (4) (C)	History of World Arch: 18th C to Present ARCH 219 (4)		Small Scale Structures ARCE 315 (4)	Structural Integration in Architecture ARCE 316 (4)	Professional Elective (4)			Professional Elective (4)		
Calculus I MATH 141 (4) (B1)	Calculus for Architecture and Construction Management MATH 182 (4) (B1)	GE (4)	Structures I ARCE 211 (3)	Structures II ARCE 212 (3)	Introduction to Structural Systems ARCE 226 (3)		Professional Elective (1)	Professional Elective (1)	Professional Elective (4)			Professional Elective (4)		
Expository Writing: ENGL 133 or JLN (4) (A2)														
Oral Communication: COMS 101 or 102 (4) (A2)														
Reasoning, Argumentation, & Writing (A3) COMS 124, COMS 146, 145, 146, 148, or PHIS 212 (4) ** Can be taken anytime between Winter of Freshman and Winter of Sophomore Years.														
17	17	17	16	16	16	15	15	15	13	13	13	12	12	12
Legend:												TOTAL: 225		
Course Title												Major (122)		
Course # (Unit#)												Support (15)		
[(C) Coreq]												General Ed. (88)		

Fig. 3: Bachelor of Architecture Flowchart diagram with six Architectural Technology courses highlighted. The six courses must be taken in order, and are co-requisite with the Architectural Design studios, shown directly above the highlighted courses.

Site & Contextual Systems

The Site and Contextual Systems modules introduce methods of reading and responding to a variety of situational typologies from densely bound urban contexts to more open rural sites with varied landform. The fall module is based around an urban context and introduces the physical and legal determinants of city form, including those regulated by local city zoning regulations. The fall term offers frameworks for developing a meaningful architectural interface between the building and public rights-of-way; understanding architectural form as a component of the larger urban fabric and the value of contemporary public space. The winter term module engages a rural, or sub-urban, site including a sloped topography and offers an introduction to land form, morphology, and hydrology. Class discussions provide a framework for considering the physical connection between building and ground. Class exercises introduce students to techniques of grading and drainage and present concepts of accessibility and site circulation. The spring term module focuses on methods of constructing landscape assemblies such as paving and walls as well as offering a framework for considering planted-form in architectural contexts.

Energy & Environmental Systems

The Energy and Environmental Systems modules focus on passive, climate appropriate, strategies for human thermal comfort and health. The fall module introduces students to climate, bioclimatic resources, and takes a deep look at the solar energy. The focus is on daylighting for health and energy efficiency and assignments promote students as informed designers of daylight. Physical daylighting models are used to experiment with, and light effects are captured quantitatively with light meters and qualitatively with photography. In the winter, the psychrometric chart is employed as a guide for passive heating and cooling design strategies. Over several weeks, each region of the psychrometric chart is unpacked with vernacular and contemporary examples of

how buildings can both overcome and benefit from outdoor temperatures, humidity, and winds. A case-study project is carefully drawn by students in order to document the project's climate and formal and material responses. In the spring term, a closer examination of the building envelope reveals ways in which designers have been inventive with the layers of material commonly utilized to separate interior from exterior environments. By systematically working from thin envelopes to thick envelopes, students see how layers can be separated to create partially thermally controlled occupiable spaces, and how these spaces enrich the experience and aesthetics of buildings and cities. Students are asked to propose an envelope system for their design studio project as the culmination of their learning over the year.

Material & Building Systems

The Material and Building Systems modules introduce students to the properties of materials and the principles of assemblies while connecting these considerations to issues of site systems and energy systems. In the fall quarter, assembly systems are introduced to students as building elements such as foundations, walls, frames, roofs and envelopes. By discussing assembly systems as building elements students are introduced to contemporary systems thinking, but also to 18th century theories regarding conception and construction established by Semper and others. Students are also introduced to other important factors that influence material and assembly decisions such as life safety requirements and building codes. In the following two quarters, the phenomenal as well as the performative aspects of materials are discussed in terms of properties and composition. To underscore the importance of resource conservation and environmental responsibility, the courses present the origin and manufacture of materials so that life-cycle implications may be understood. Taken together, these discussions on material and assembly systems strive to help students consider beautiful, ethical and responsible ways to

approach their own design work in second year while providing a scaffold for more in-depth study of material and tectonic issues in subsequent courses. Case study projects, which link together concepts from Site and Environmental Systems, are completed each quarter, beginning with simple diagramming in the fall, then moving into more detailed building sections, plans, and 3D representations in the subsequent quarters.

Assessing Success through Laboratory Exercises and Exams

How can we know if we have been successful? While we feel a responsibility to align the architectural education with innovations in contemporary practice; namely an

increased capacity to consider complex technologies relative to rather than in isolation from each other, we struggle with the most appropriate methods of assessing the success of our curricular changes. Likely, the best indication of success will be available after our students enter the discipline, and have had a chance to understand how their education has prepared them for practice. At best, we might see results after a year or two, when our past students can be assessed by faculty in later years of our curriculum. We hope that our paper presentation can incite a dialogue about assessment tactics with colleagues outside of our own university. However, in the short term, we currently assess our own through a review of student laboratory exercises and exam results. Following is a sample of each.

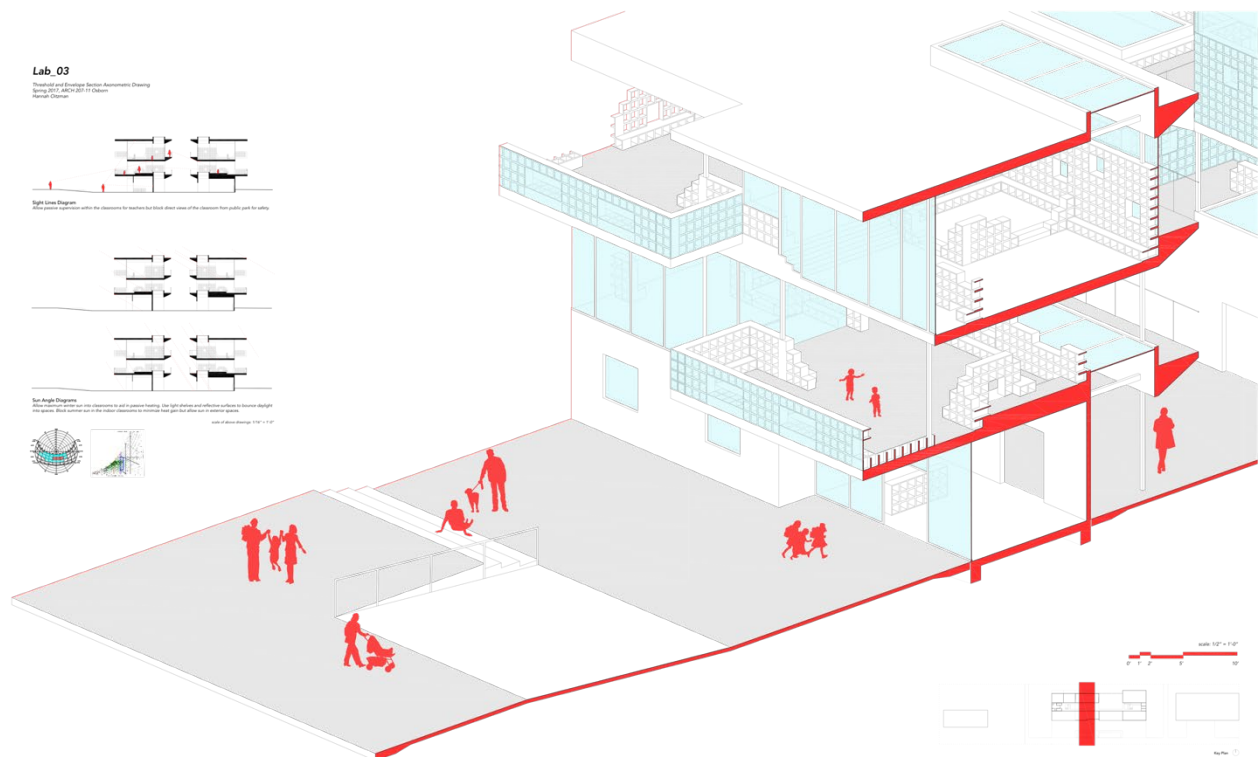


Fig. 4: Sample laboratory assignment asking students to develop an enclosure system and entry threshold. Work by 2nd year student Hannah Oitzman

As mentioned previously, students are asked to propose an envelope system for their spring-term design studio project as the culmination of their learning in the second-year technology courses (*Fig. 4*). Architectural envelopes negotiate complex sets of considerations—forming a physical boundary between outside climate and interior comfort, negotiating material selection and building assembly methods, and accommodating both physical and experiential access to the site and surrounding context. Through a schematic building envelope design, students are asked to develop an entry threshold that delineates a sequence of space—from exterior to interior and from public to private, and to articulate a physical boundary between interior and exterior that negotiates both separation (exterior climate vs interior comfort, natural environment vs tempered environment, sunlight vs daylight, etc.) and continuation (passive heating and cooling, ventilation, natural light, views, etc). Articulated through a building section-axonometric, the sample of student work shown below is successful in delineating interior from exterior space using the convention of *poché*. Basic material differences, such as glazing versus a potentially insulated wall or floor assembly, are identified through thickness. Strategies for passively accommodating human thermal comfort, namely solar shading in this case, are explored through a series of diagrams and are further evident in the long horizontal overhangs designed for the south façade of the proposed building. Finally, the interior programmatic spaces are drawn relative to the city beyond, and a sequence of movement from outside to inside is implied. While a successful level of understanding for a second-year student can be represented by a building section, the expectation is that this student is able to work intelligently at the level of detail requisite of a wall section by the end of third year study.

Multiple-choice exams have been used in the Architectural Technology courses at Cal Poly for decades. In the second iteration of the piloted new

Architectural Technology courses, the instructors of the integrated large lectures decided to make a change in the testing strategy. The tests needed to be more meaningful to students. Instead of short-term memorization of a lot of concepts, the tests should be more like real life, and incidentally more like the updated ARE. We decided to make the transition from multiple-choice midterm exams of 30-40 questions, to vignette and essay questions with 3 to 5 questions. The final comprehensive exam changed from 70+ questions, to just 6 questions. Ironically, the time to complete the exams increased. While there are now fewer questions, students must work harder and use a variety of digital and analog resources to facilitate proposed solutions to problems. Instead of selecting from a menu of possible choices, some of them rather minor points, students were now asked to utilize codes, texts, notes, and previous assignments to work through complex parameters and provide technically sound design proposals. The new exams challenge students to think as critically as architects, which is a shift from the previous exams which asked students to perform as test takers.

The fall quarter is now taught with three modules: Urban Sites, Solar Geometry & Daylighting, and Building Elements. The final exam asks students to bring these concepts together, by asking a series of questions that are all linked together. In the first question a site and program are given and students are asked to use the City Zoning Code (which they must find and navigate themselves) in order to determine the allowable building envelope. They sketch the envelope in axonometric in the exam, providing their calculations for lot coverage and allowable area. In the next question, they determine the allowable construction types using the Building Code (which again they must find and navigate). Then they are asked to calculate the live loads, dead loads, and do a preliminary foundation size in order to determine if a shallow foundation system is viable for the given program and site. In the final questions, they are asked to re-

evaluate their building massing given additional information and a requested change from the hypothetical client. For the last questions, they must read the polar sun path chart, calculate shadow lengths,

sketch the shadows on a site plan, and redraw the massing in order to best position the building and the outdoor space in response to solar availability. Four sample pages from the exam are shown below (Fig. 5).

Q2 Building Envelope Study
8 points total
 Create (1) building envelope study that accommodates the yards, building height, lot coverage, and floor area ratio restrictions that you identified in Q1.

3 pts A) Sketch the **Building Envelope** in axonometric view using the base grid provided for you on the following page. Be sure to label the yard setbacks, and final building dimensions (length, width, and height) within the sketch.

4pt (1pt for each calc) B) Calculate the **floor area and lot coverage** for both the **allowed and proposed scenarios** in order to demonstrate that your proposed envelope is allowed by the zoning code. Show all of your calculations in the space provided.

1pt C) Provide a **one-sentence description** of how your proposed building envelope is permitted by the zoning code.

Assumptions:

- The property is 120'-0" along Pacific and 100'-0" along Marro Street.
- Each floor of the building must have a minimum height of 10'.
- The director of the daycare has determined that there is adequate street parking available and so no parking is required on-site.

Pacific Street
120'-0"

100'-0"
Marro Street

971 Pacific Street
1/64" = 1'-0"

Q3 Allowable Construction Types
4 points total
 The day care center from the previous questions, due to its size and number of students, is classified as an I-4 occupancy. Use the tables from **Chapter 5 of the 2016 CA Building Code** to answer the following questions.

1 pt A) Based on your axonometric sketch, **list the building type or types** that are **NOT** allowed given your scheme's **building height**:
 1 Story: None. All types allowed based on height.
 2 Story: None. All types allowed based on height.

1 pt B) Based on your axonometric sketch, **list the building type or types** that are **NOT** allowed given your scheme's **number of stories**:
 1 Story: None. All types allowed.
 2 Story: Type V A + B.

1 pt C) Based on your axonometric sketch, **list the building type or types** that are **NOT** allowed given your scheme's **floor area**:
 1 Story: Less than 9,000 sf. None. All types allowed.
 2 Story: Greater than 13,000 sf. Type II B, Type II R, and Type V B.

1 pt D) Considering results from all three of the above criteria, which of the allowable construction types would probably be the **least expensive**?
 1 Story: Type V A or B
 Type IIIA or Type IV

Q4 Siting Shallow Foundations
15.5 points total
 Your client for the day care center is interested in pursuing the scenario you **sketched in question 2**. As a first step toward determining the constructability of the proposed building, you develop a preliminary shallow-foundation design. **You must show your calculations and units to receive credit for parts B-E of this question.**

5 pts A) Sketch a **floorplan and section of your proposed massing**. Label perimeter and height dimensions. Wall, roof, and floor assembly systems are provided in Table D on the following page. Label the wall, roof, and floor materials in your sketches.

1 pt B) What is the total linear perimeter of exterior bearing wall? Show calcs and units.
 $2A + 2B = Perimeter in linear feet.$

Building Envelope Study
 1/32" = 1'-0"

Provide a one-sentence description of how the building envelope study satisfies the local zoning code:
 After setting the building back per the street and side yard requirements, a 7,200 sf footprint was located within the allowable building area. In order to make the largest building possible, a two-story massing is proposed with each floor at 7,200 sf, for a total building area of 14,400 sf, which is less than the allowable floor area of 18,000 sf.

Show your calculations and units:

Allowable Coverage:
 $120' \times 100' = 12,000 \text{ sf} \times 0.60 = 7,200 \text{ sf}$

Proposed Coverage:
 $75' \times 96' = 7,200 \text{ sf}$

Allowable Floor Area:
 $12,000 \text{ sf} \times 1.5 \text{ FAR} = 18,000 \text{ sf}$

Proposed Floor Area:
 Most common correct answer:
 $7,200 \text{ sf} \times 2 \text{ flrs} = 14,400 \text{ sf}$
 *7,200 was also accepted for a 1 story building

Name: _____ Activity Instructor: _____ Activity Section: _____

2 pts D) The **five existing trees** on the site will all provide desirable shade during summer recesses. **Determine the shadow lengths** for these trees. Tree heights are labeled on the site plan below. If using a graphic method, label all angles and dimensions. If using the trig method, show units.

4 pts E) **Sketch and label the listed items.** Pay attention to the direction of the north arrow. Sketch summer recess shadows from the five existing trees on site. Label azimuth angles and shadow length. Sketch a proposed location for a Summer Play Area with ample shade. The play area should be a minimum of 30'x30'.

4 pts F) **Sketch a revised building footprint** that accommodates both the proposed summer and winter play areas. Be mindful of the setback requirements you determined from the Planning Code. **Label the revised building footprint with the area per floor, the number of stories, and the total building area.** Remember that your goal is match the proposed calculated area from Question 2.

Site Solar Study
 Scale: 1/32" = 1'-0"

Fig. 5: Sample pages from the Fall Quarter 2017 final examination showing integration of course topics. Red text shows correct answers that would not have been provided to the student taking the exam.

Notes or References:

- 1 Warren Weaver, author of "Science and Complexity" (*American Scientist*, 36: 536, 1948), was quoted extensively by Jacobs in "The kind of problem a city is". In his essay Weaver defines three types of problems that faced physical scientists since the 17th century: problems of simplicity, problems of disorganized complexity and problems of organized complexity.
- 2 Weaver defined problems of organized complexity as those "problems which involve dealing simultaneously with a sizable number of factors that are interrelated into an organic whole."
- 3 <https://www.ncarb.org/about/history-ncarb/history-are>
- 4 Ibid.
- 5 Jared Zurn, AIA, and director of examination at NCARB refers to the difference between the vertical and horizontal organization in Steve Cimino's, "A New Era of Exams". *Architect Magazine*. November 2016.
http://www.architectmagazine.com/aia-architect/aiaknowledge/a-new-era-of-exams_o