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Work in Progress: Professional Engineers' Reflections on Design Decision-Making: Implications for Engineering Education

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Abstract

This work-in-progress paper explores the gap between the idealized design models taught in engineering curricula and the multifaceted realities of professional practice. While academic problems often prioritize theoretical optimization, practicing engineers must navigate complex trade-offs involving budgets, time pressures, and stakeholder demands. To address this, the study utilizes a constructivist grounded theory approach, analyzing interviews with 11 civil and structural engineers to identify how practitioners make decisions under real-world constraints. Preliminary analysis reveals that professional mindsets prioritize pragmatic compromises and iterative decision-making over academic ideals, emphasizing resilience and values-aligned trade-offs. These findings suggest that engineering pedagogy should evolve by integrating case-based simulations and reflective prompts that replicate authentic industry pressures. By embedding these practitioner-informed insights into the curriculum, educators can better prepare students for industry and foster the adaptive design mindsets necessary for lifelong professional success.

1. Introduction

Engineering graduates often struggle to move from academic design environments to the complex, constraint-laden settings of professional practice. Although foundational studies emphasize that real engineering involves uncertainty, negotiation, and situated judgment [1], [2], many students complete capstone with a more linear and optimization-focused view of design. Addressing this school–to–work gap remains essential for preparing adaptable, practice-ready engineers.

Capstone and senior design courses aim to support this transition, yet their structure and authenticity vary widely. Classic reviews document diverse models, from faculty-scoped projects to industry-sponsored and competition-based formats [3], [4]. Subsequent research highlights gains in teamwork and communication [5], while national surveys reveal persistent variability in realism across programs [6], [7]. Even courses positioned as "authentic" often simplify cost, stakeholder, or constructability constraints due to curricular limitations, leaving students with partial exposure to the realities of professional design work.

These gaps motivate the present study. By examining how practicing engineers describe design decision-making, we aim to illuminate the complexities and trade-offs characteristic of real practice and identify insights that can inform more authentic design pedagogy.

- RQ1. How do engineers characterize their design decision-making in real-world contexts?
- RQ2. What gaps or tensions emerge when comparing professional design practice to academic experiences such as capstone?
- RQ3. How can practitioner insights inform more authentic and transferable design pedagogies in engineering education?

2. Methodology

2.1 Methodology Intro and Research Paradigm: Constructivist Grounded Theory

This work-in-progress study is part of a larger constructivist grounded theory project examining how practicing engineers make design decisions and how those decisions relate to identity and motivation. The methodology reflects established grounded theory practices emphasizing iterative, comparative, and emergent analysis. This study is guided by constructivist grounded theory [8], [9], which emphasizes iterative data collection and analysis, researcher reflexivity, and the co-construction of meaning with participants.

2.2 Participant Recruitment and Sampling Strategy

Participants were recruited through professional networks connected to the project's PIs. Purposive sampling targeted practicing civil and structural engineers at any career stage, followed by early theoretical sampling to explore emerging categories. Participants included mid-career (approximately 8 years of experience) and senior-level engineers (over 30 years of experience), all licensed as Professional Engineers (PE) working within civil and structural practice settings. This WIP paper draws on 11 interviews (n=11), representing diverse roles and firm types.

2.3 Data Collection

Data were collected through semi-structured interviews, each lasting 50–75 minutes, conducted via Zoom. All interviews were audio-recorded and human-transcribed for accuracy.

Interviews followed a semi-structured protocol designed to elicit experiences related to professional identity, motivation, and design practices. This approach ensured consistency across interviews while still allowing participants to direct the conversation toward meaningful experiences. While the full protocol is not included in this WIP, example questions included:

- *"Could you walk me through a project that represented your approach to engineering?"*
- *"What tensions or trade-offs did you encounter in that project?"*
- *"How do you typically approach a new design challenge?"*
- *"How has your identity as an engineer shaped the way you engage in design?"*

2.4 Data Analysis

Analysis followed grounded theory procedures [8] using MAXQDA software to facilitate coding, memoing, and visualization. The process was inductive, allowing concepts and categories to emerge directly from the data—primarily interview transcripts—through constant comparison. Initial (open) coding involved section-by-section analysis of transcripts to identify preliminary patterns and generate in vivo codes grounded in participants' own words. Focused coding then refined and consolidated these into more selective conceptual categories. Initial coding generated numerous in vivo and process-oriented codes, which were iteratively refined and consolidated through focused coding into the three major theoretical categories presented here. Then, theoretical coding explored interconnections among the emerging categories. Throughout, memo writing captured analytical insights and emerging ideas, while diagramming in MAXQDA supported the iterative development of the emergent theoretical framework.

2.5 Trustworthiness and Rigor

To support credibility and transparency, we used established trustworthiness strategies. These included peer debriefing of coding and analysis, the primary researcher's reflexive memoing on assumptions and analytic decisions, and maintaining a detailed audit trail of transcripts, codes, and memos [10]. Together, these practices ensure methodological rigor consistent with CGT.

3. Preliminary Findings

Early analysis showed that engineers' design decision-making is shaped by nested layers of constraints and professional judgment that extend well beyond the optimization-oriented models emphasized in academic settings. Participants described design as an iterative negotiation among competing forces—values, feasibility, constructability, stakeholder needs, and regulatory conditions—rather than a linear sequence of steps. To represent these dynamics, we developed a preliminary visual representation (Figure 1) in which the engineer's internal reasoning sits at the core, surrounded by layers of constraints that continually influence and reshape decisions.

3.1 Overview of Major Theoretical Categories

Figure 1 organizes the major theoretical categories that emerged from participants' description of design work, highlighting multiple layers of influence that engineers reference across interviews. Although analytically separated here, participants emphasized that these layers operate simultaneously and often in tension with one another during real projects.

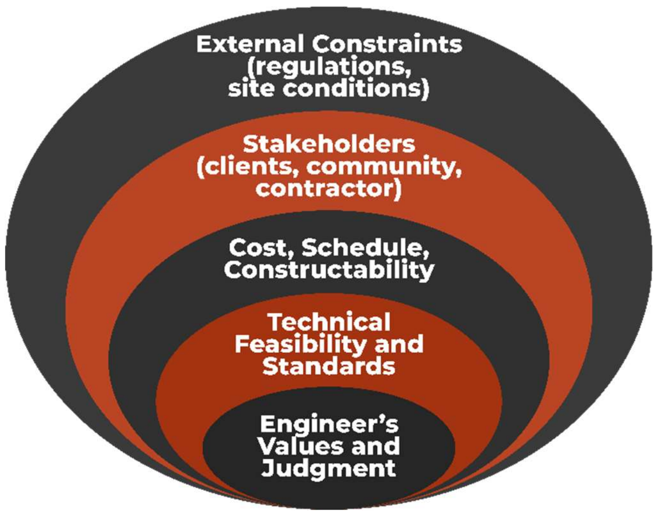

Fig 1. *Working draft of theoretical categories illustrating how practicing engineers describe navigating nested layers of constraints during real-world design decision-making*.

At the core is the engineer's values and professional judgment, which participants described as the foundation for decisions involving ethics, safety, responsibility, and personal standards of quality. Surrounding this is the technical layer, encompassing codes, standards, calculations, and engineering analysis. Participants noted that while these technical elements establish what is feasible, they seldom determine the final decision on their own. A third layer includes practical constraints such as cost, schedule, and constructability—factors that frequently drive modifications to technically optimal solutions. The next layer reflects stakeholder dynamics: clients, contractors, regulators, and community members whose needs and expectations shape design choices and introduce competing priorities. Finally, the outer contextual layer includes regulatory environments, site conditions, organizational practices, and political considerations that frame project boundaries from the outset. Together, these layers form a nested structure that illustrates the multidimensional reasoning engineers use as they navigate trade-offs, coordinate across disciplines, and adapt to evolving project conditions [11], [12]. The following recurring themes describe the specific mental processes and professional mindsets engineers employ to navigate these nested layers of constraints.

3.2 Recurring Theme 1: Pragmatic Compromise Over Theoretical Optimization

Participants contrasted classroom ideals of optimal solutions with compromises required in practice [11]. Decisions were often driven by fabrication and cost considerations. As P04 noted, *"In school it was all about minimizing use of material… In practice it's been minimize the labor. If every diagonal and vertical is a different member size, fabricators will string you up."* Budget limitations also constrained choices; P13 explained, *"The 'best' design might be an interchange… but because it's so expensive, we may settle on a roundabout that's safer but not as efficient."* Engineers emphasized ambiguity rather than singular solutions. As P14 put it, *"Plans are never perfect… young engineers think there's one solution. In practice there's a menu of solutions."*

3.3 Recurring Theme 2: Iterative Decision-Making Under Uncertainty

Engineers described design as cyclical and shaped by shifting constraints. Time pressure required continual adjustments; P15 stated, *"Schedule is the driver… we make compromises on fidelity of design and pay premiums for expedite fees."* Field conditions also prompted rapid redesign. P12 recalled, *"The contractor told me, 'Yeah, I cut the dowels… I'm hoping you can give me an epoxy solution.'"* Internal coordination challenges added further iteration. As P12 noted, *"We made the mat thicker… now everything for the tank manufacturer doesn't work and we're redesigning, wasting fee."*

3.4 Recurring Theme 3: Values-Aligned Trade-Offs and Resilience

Participants highlighted the role of values in decision-making. Ethical responsibility shaped choices, as P12 described: *"They said, 'What if we just don't upgrade that?' And I said… 'Now I've seen it, so you can't not upgrade it.'"* Engineers also balanced quality with business pressures; P10 noted, *"We trade off getting the job done versus making a profit… Young engineers think there are more 'hard' trade-offs than there really are."* Commitment to community was also evident. P01 shared, *"If you close the highway down to 15 feet, trucks can't get through… figuring out how to get those folks through."* P15 emphasized personal well-being: *"It's too easy to say yes to every challenge… not knowing when to say 'enough.'"*

3.5 Cross-Case Comparisons

These recurring themes appeared consistently across roles, firm types, and experience levels. No participant described design as linear or purely technical; all emphasized navigating constraints, coordinating with stakeholders, and drawing on personal judgment.

4. Discussion

4.1 Confirming and Extending Existing Understandings of Engineering Practice

The preliminary theoretical categories visual (Figure 1) illustrates how pragmatic compromise, iterative reasoning, and values-aligned judgment operate as intertwined layers of practice. This structure aligns with classic accounts of engineering as situated and contingent [1] but extends them by positioning engineers' internal values and identity at the core of decision-making rather than as peripheral influences [13], [14]. Early findings suggest that moral commitments, professional standards, and personal judgment anchor choices across technical and practical layers. These findings also contrast with linear, stage-based representations of design processes often emphasized in academic instruction.

4.2 Implications for Engineering Identity and Motivation

Participants' accounts show that identity formation is shaped as much by ethical agency and relational judgment as by technical proficiency. Experiences such as advocating for safety, negotiating client pressure, or balancing community needs reflect autonomy and purpose—key components of sustained motivation. Discussions of boundary-setting and emotional labor highlight aspects of agency seldom addressed in coursework. Explicitly incorporating these dimensions into design education may better support the development of resilient, values-aligned professional identities.

4.3 Working Set of Theoretical Categories Related to Professional Design Mindsets

The categories summarized in Figure 1 provide an initial analytic lens for describing the types of considerations engineers raised when discussing complex design work:

- **Core** (Values & Judgment): Ethical responsibility, identity, and resilience.
- **Technical** (Feasibility & Standards): Codes, analysis, physical constraints.
- **Practical** (Cost, Schedule, Constructability): Factors that reshape technically sound options.
- **Stakeholder** (Clients, Contractors, Community): Negotiation among various expectations.
- **Contextual** (Regulations, Site, Politics): External factors that bound decisions.

These categories highlight design as multidimensional reasoning rather than linear problem solving and suggests that developing professional design mindsets requires integrating ethical, communicative, and adaptive capacities alongside technical skills [15], [16].

4.4 Current Analytic Status and Ongoing Work

This work-in-progress reflects an early stage of grounded theory development rather than a saturated model [18]. While the categories identified here appeared consistently across the current set of civil and structural engineering interviews, additional theoretical sampling across disciplines will help probe remaining analytic gaps and refine relationships among the theoretical categories' layers. Continued focused and theoretical coding will deepen insight into how identity, motivation, and design practices intersect and inform future pedagogical translation.

5. Pedagogical Implications & Recommendations

The findings show that professional engineering design involves nested layers of values, technical feasibility, resource constraints, stakeholder needs, and contextual pressures—conditions that differ from many academic design settings. This section outlines practical, scalable strategies for integrating these realities into coursework.

5.1 Capstone Authenticity Varies Widely

Although some capstone courses include client interaction or open-ended problems, many still provide stable scopes, ample resources, and predictable timelines [5], [17]. Instructors often simplify complexity to fit academic schedules or ensure equitable experiences, leaving students with limited exposure to the uncertainty, negotiation, and values-based decisions common in practice. Recognizing this variability enables educators to deliberately introduce structured complexity even within instructor-scoped formats.

5.2 Strategies for Integrating Real-World Complexity

A capstone experience aligned with these findings would incorporate structured mid-project constraint shifts (e.g., scope changes, budget adjustments, or regulatory updates), require explicit documentation of trade-offs across technical, stakeholder, and ethical dimensions, and include guided reflection on professional identity and decision-making under uncertainty. Rather than treating constraints as fixed, projects would simulate evolving conditions that require negotiation and adaptation. Assessment would prioritize the quality of reasoning, communication, and responsiveness to competing priorities—not solely final technical performance—thereby more closely approximating the multidimensional conditions described by practicing engineers.

5.3 Implementation and Scalability

These strategies can be incorporated with minimal disruption to existing course structures. In most cases, instructors can introduce a single constraint change, trade-off matrix, or stakeholder scenario without altering project scope or learning outcomes. Effective implementation centers on evaluating the quality of students' reasoning—how they justify decisions, communicate implications, and navigate competing priorities—rather than solely the final design. To support scalability, departments can develop shared libraries of constraint scenarios, role-play profiles, and reflection prompts that instructor can adapt across disciplines. Embedding these elements across multiple design courses can create a coherent progression in which students repeatedly engage with the layered complexity characteristic of professional practice.

6. Conclusion

6.1 Contribution to Design Education and Professional Formation

This study provides an empirically grounded view of how practicing engineers navigate real-world design complexity. The preliminary theoretical categories synthesize early insights into a framework that foregrounds the interplay of values, technical reasoning, practical constraints, stakeholders, and context. These findings highlight the need for design education that prepares students for multidimensional, ethically anchored decision-making.

6.2 Next Steps for the Larger Study

Future work will extend theoretical sampling beyond civil and structural engineering to capture a broader range of professional contexts and validate the emerging categories across disciplines. Continued focused and theoretical coding will refine relationships among the layers, deepen understanding of how identity and motivation intersect with design practice, and identify additional pedagogical leverage points. Follow-up interviews will also explore how engineers' decision-making evolves over time and across career stages.

6.3 Call for Practitioner-Informed Pedagogy Across Engineering Disciplines

Based on preliminary results, we encourage engineering programs to embed structured opportunities for trade-off negotiation, stakeholder engagement, and reflective practice across curricula—not only in capstone. Integrating practitioner-informed insights can better align educational experiences with the realities of engineering work and support the formation of adaptive, ethical, and resilient designers.

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