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Integrating Sustainable Project Management Frameworks into Construction Research and Education: Bridging STEM Methodologies with Real-World Practice

Dr. Esra Tepeli PhD, PMP, Purdue Polytechnic Institute, Purdue University – West Lafayette

Dr. Esra Tepeli is a Clinical Assistant Professor in the School of Construction Management Technology at Purdue University. She holds a Bachelor of Science degree in Civil Engineering, a Master's degree in Construction Management with a double major in project and risk management, and a Ph.D. in Construction Project Management and Risk Management. Her doctoral research focused on managing complex and strategic construction projects, including Public-Private Partnerships (PPP), design-build-maintenance, and large transportation projects. At Purdue, Dr. Tepeli teaches courses in contract administration and specifications, strength of materials, and quantity takeoff, with a strong emphasis on experiential and industry-integrated learning. Her teaching and research interests include project and risk management, Lean Construction, sustainable construction, and the integration of emerging technologies such as BIM, cloud-based project management tools, and AI into construction education. Dr. Tepeli is an active member of the Project Management Institute (PMI) and holds the Project Management Professional (PMP) credential. She has conducted professional trainings, contributed to outreach initiatives, and presented at global conferences hosted by PMI chapters. She is also preparing a Lean Construction Certificate in collaboration with the Lean Construction Institute (LCI). Her work actively bridges academia and industry to enhance student engagement, retention, and workforce readiness.

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Esra Tepeli, PhD, PMP, RMP

Purdue University, Construction Management

Abstract

The construction industry faces the dual challenge of delivering projects efficiently while advancing environmental and social sustainability objectives. Sustainable project management (SPM) frameworks integrating lifecycle thinking, stakeholder value, governance discipline, and transparency have been extensively developed in professional and organizational contexts. However, the systematic operationalization of these frameworks within undergraduate construction research and education environments remains underdeveloped. Construction management (CM) education often introduces sustainability, Lean planning, Agile cycles, and governance principles as discrete conceptual domains rather than embedding them within a coherent, enactable delivery system aligned with authentic research workflows. This paper presents the Sustainable Research Project Delivery (SRPD) framework as an operational integration architecture that adapts established Lean Construction, Agile/hybrid, and principle-based project management mechanisms into a structured undergraduate research workflow. SRPD does not propose a new sustainability taxonomy. Instead, it specifies how existing evidence-based frameworks can be assembled into a layered system of artifacts, governance routines, milestone planning structures, sustainability checkpoints, and performance metrics tailored to semester-bounded research contexts. The framework was developed and refined through a Design-Based Research (DBR) methodology and piloted within faculty-led construction and infrastructure sustainability research projects involving undergraduate teams. Mixed-method evaluation incorporated artifact repository analytics, delivery reliability indicators, revision counts, sustainability reasoning rubrics, collaboration surveys, and qualitative reflections. Preliminary pilot findings indicate improved role clarity and accountability, earlier identification of workflow constraints, increased planned-versus-completed task reliability, reduced late-stage rework signals, and stronger lifecycle-based sustainability articulation in student deliverables. By aligning professional project delivery routines with undergraduate research workflows, SRPD contributes a replicable operational integration architecture and transferable design principles for embedding sustainability within construction engineering education.

Keywords: Project management frameworks; Sustainable construction; Agile and Hybrid project management; Experiential learning; Construction education

1. Introduction

Construction and infrastructure projects are increasingly evaluated not solely in terms of cost, schedule, technical quality, and safety, but also according to lifecycle environmental performance, social equity, resilience, and governance transparency. The United Nations 2030 Agenda and its Sustainable Development Goals (SDGs) have heightened expectations that built-environment projects demonstrate measurable sustainability outcomes across design, delivery, and operational phases [1]. As a result, project leaders must manage technical complexity while simultaneously addressing stakeholder expectations, long-term environmental impacts, and transparent tradeoff articulation.

Sustainable project management (SPM) scholarship argues that sustainability must be embedded both within the project deliverable ("sustainability by the project") and within the processes through which projects are governed and executed ("sustainability of the project") [2], [3]. Reviews of SPM literature emphasize governance structures, lifecycle thinking, and structured decision-making mechanisms that render sustainability operational rather than aspirational [2]. Empirical findings further suggest that sustainability integration depends on contextual stimuli and institutionalized routines that make sustainability considerations visible and actionable during planning and execution phases [3]. Concurrently, professional standards such as the PMBOK® Guide, 7th edition, have transitioned toward principle-based frameworks emphasizing value delivery, stewardship, adaptability, and systems thinking [4], reinforcing the conceptual compatibility between sustainability integration and contemporary project governance approaches.

Within construction management (CM) education and undergraduate STEM research environments, however, sustainability, Lean Construction, Agile practices, and governance principles are frequently introduced as parallel conceptual streams. Agile methodologies promote iterative development cycles, rapid feedback, and transparency [5]. Lean Construction emphasizes flow reliability, constraint removal, and collaborative commitment planning [6], [7]. Experiential learning theory highlights the importance of structured reflection and authentic engagement in knowledge construction [8], while engineering education research underscores the value of collaborative learning structures in improving engagement and professional readiness [9], [10]. Despite the maturity of these domains, they are rarely enacted as an integrated delivery system within undergraduate research workflows.

Undergraduate research teams operating within semester-bounded faculty-led projects often encounter recurring coordination challenges: ambiguous task ownership, inconsistent meeting cadence, duplicated effort, delayed constraint identification, and limited traceability of sustainability-related decisions. These structural inefficiencies may inhibit meaningful sustainability integration even when students possess conceptual awareness of sustainability frameworks. In such contexts, sustainability may remain confined to final reporting sections rather than embedded within recurring planning and decision routines.

Bridging professional delivery mechanisms and undergraduate research practice therefore requires an operational architecture capable of stabilizing collaboration, externalizing decision rationale, and embedding sustainability checkpoints within routine workflow transitions. This study presents the **Sustainable Research Project Delivery (SRPD) framework** as such an architecture. The objective is not to redefine sustainable project management theory, but to specify how established sustainable PM, Lean Construction, and Agile/hybrid mechanisms can be assembled into a coherent, enactable system tailored to undergraduate construction research and education contexts.

The study is guided by **three research questions**:

RQ1: How can sustainable PM, Lean Construction, and Agile/hybrid mechanisms be operationally integrated into a coherent delivery architecture for undergraduate construction research teams?

RQ2: What observable effects does implementation of this integrated architecture have on collaboration quality, delivery reliability, rework signals, and sustainability reasoning within semester-based research projects?

RQ3: What design principles and curricular integration strategies support scalable adoption of structured sustainability-oriented delivery mechanisms across construction research and education settings?

To address these questions, the SRPD framework was developed and refined through a Design-Based Research methodology conducted within authentic faculty-led sustainability research projects. By aligning professional project delivery routines with undergraduate research workflows, the framework seeks to strengthen both sustainability literacy and coordination discipline in construction engineering education.

2. Background and related work

Sustainable project management (SPM) extends traditional project performance evaluation beyond the “iron triangle” of cost, schedule, and scope to incorporate environmental stewardship, social responsibility, and long-term value creation [2]. Marcelino-Sádaba et al. [2] propose that sustainability integration requires embedding environmental and social considerations across project governance structures and lifecycle phases rather than treating them as peripheral compliance requirements. Silvius and Schipper [3] further demonstrate that sustainability-oriented behavior among project managers depends not only on conceptual awareness but also on contextual stimuli and institutionalized routines that make sustainability considerations actionable during planning and execution.

Within professional settings, sustainability frameworks often emphasize lifecycle assessment, stakeholder mapping, governance transparency, and structured tradeoff evaluation. However, translating these principles into operational routines remains challenging even in mature organizations. Sustainability objectives frequently compete with short-term delivery pressures, and without explicit integration into planning and control systems, sustainability considerations may be marginalized during execution [3].

The PMBOK® Guide, 7th edition, reflects a broader shift toward principle-based management that emphasizes stewardship, systems thinking, and value delivery across project lifecycles [4]. This evolution aligns conceptually with SPM scholarship and provides an institutional foundation for integrating sustainability within project governance and delivery structures. Nevertheless, professional standards typically assume experienced practitioners operating within formalized organizational infrastructures. Undergraduate research environments differ substantially in structure, authority distribution, and temporal constraints, requiring adaptation of these principles.

Lean Construction, grounded in production theory and the elimination of waste, emphasizes flow reliability, value generation, and constraint management [6]. Koskela’s production theory critiques traditional project management paradigms for neglecting flow variability and proposes systematic approaches for improving production stability [6]. The Last Planner System (LPS) operationalizes Lean principles through collaborative pull planning, lookahead planning, weekly commitment cycles, and measurement of reliability metrics such as Percent Plan Complete (PPC) [7].

Although originally developed for construction production environments, Lean mechanisms are applicable to knowledge-intensive workflows characterized by interdependencies, uncertainty, and iterative refinement. In research settings, variability manifests as delayed information, unclear dependencies, evolving scope definitions, and asynchronous contributions. Structured commitment planning and constraint logging may therefore enhance reliability and reduce rework even in non-physical production contexts. However, Lean principles alone do not explicitly address sustainability reasoning or lifecycle tradeoff articulation. Integrating Lean reliability mechanisms with sustainability checkpoints requires additional governance and documentation structures capable of linking flow discipline with sustainability intent.

Agile methodologies, originating in software development, emphasize iterative delivery, adaptive planning, transparency, and continuous improvement [5]. Short feedback cycles and retrospectives promote learning under uncertainty and enable incremental refinement. While fully Agile delivery models may be constrained in traditional construction contexts due to contractual structures and physical sequencing, hybrid approaches combining milestone governance with iterative cycles have gained traction in complex project environments.

In research workflows, iterative development is intrinsic to literature synthesis, methodological refinement, data analysis, and interpretation. Integrating Agile-inspired sprint reviews and retrospectives within research teams may therefore enhance transparency and adaptive learning. Yet Agile routines require alignment with governance discipline and performance measurement structures to prevent drift and ambiguity, particularly in student-led environments.

Experiential learning theory conceptualizes learning as a cyclical process of experience, reflection, conceptualization, and experimentation [8]. In engineering education, active and cooperative learning structures have been associated with improved engagement, deeper conceptual understanding, and enhanced professional readiness [9], [10]. Construction management programs increasingly incorporate project-based learning, capstone projects, and research apprenticeships to foster experiential engagement.

Despite these advances, undergraduate research experiences often vary in structure and delivery discipline. In the absence of explicit governance scaffolding, students may struggle with task prioritization, dependency management, and sustainability articulation. Sustainability concepts may be introduced within lectures or readings but not embedded within recurring project routines.

The literature establishes robust foundations for sustainable project management [2], [3], Lean reliability mechanisms [6], [7], Agile iteration [5], and experiential learning [8]–[10]. However, existing scholarship seldom specifies how these traditions can be operationally integrated into a coherent architecture tailored to undergraduate research teams.

In organizational contexts, sustainability integration is supported by formal governance systems, experienced managers, and institutional accountability structures. Undergraduate research environments differ fundamentally: authority is distributed between faculty and students, timelines are constrained by academic calendars, and team composition may change across semesters. Without structured integration mechanisms, sustainability may remain a conceptual overlay rather than a routine decision driver.

The Sustainable Research Project Delivery (SRPD) framework addresses this integration gap by assembling established frameworks into a layered operational architecture. Rather than introducing new sustainability constructs, SRPD focuses on enactment: how governance artifacts, milestone structures, Lean reliability metrics, and sustainability checkpoints can function collectively within undergraduate research workflows.

3. Conceptual framework and operational integration

3.1 Conceptual positioning and meaning of "integrating frameworks"

The Sustainable Research Project Delivery (SRPD) framework is positioned as an operational integration architecture rather than a new sustainability methodology. Sustainable project management, Lean Construction, Agile iteration, and principle-based governance are well-established traditions with distinct theoretical lineages [2]–[7]. SRPD does not redefine these traditions. Instead, it specifies how their complementary mechanisms can be assembled into a coherent, enactable delivery system tailored to undergraduate construction research environments.

In this study, "integration" refers to the coordinated enactment of planning structures, governance routines, sustainability checkpoints, and performance measurement mechanisms within recurring research workflows. The focus is on operational alignment: linking sustainability intent to weekly team behaviors, milestone transitions, decision documentation practices, and observable performance indicators. In contrast to high-level sustainability frameworks that emphasize principles or dimensions, SRPD concentrates on enactment through artifacts and routines embedded in research-phase transitions.

Undergraduate research environments differ from organizational project contexts in several ways. Authority is distributed between faculty and students; team composition may change between semesters; time horizons are constrained by academic calendars; and methodological expertise is unevenly distributed. These conditions necessitate a structured yet adaptable architecture capable of stabilizing coordination while preserving learning autonomy. SRPD is therefore designed as a layered operating system that aligns sustainability reasoning, governance discipline, and delivery cadence within semester-based research contexts.

3.2 Layered Architecture

The SRPD framework is organized into four interrelated layers: sustainability intent and performance, governance and coordination, delivery mechanisms, and measurement and learning. **Figure 1** illustrates the layered structure as an integrated stack linking sustainability goals to execution routines and evaluation loops.

The sustainability intent layer establishes lifecycle boundaries, stakeholder value considerations, and SDG-aligned performance indicators [1]–[3]. Rather than prescribing alignment with a specific rating system, the framework remains rating-system-agnostic. Teams are required to articulate the lifecycle stage(s) influenced by their research outputs, identify relevant environmental or social indicators, and document tradeoffs explicitly in structured decision logs. This approach emphasizes traceability of reasoning rather than compliance with predetermined certification schemes. Embedding sustainability checkpoints at milestone gates ensures that sustainability considerations are revisited at key workflow transitions. For example, during methodological design phases, teams must document how selected methods influence lifecycle assessment scope or data reliability. During analysis phases, teams articulate how findings inform sustainability tradeoffs or stakeholder value implications.

The governance layer formalizes role clarity, decision rights, and meeting cadence. RACI-style role maps externalize ownership and accountability, reducing ambiguity in task allocation. Structured meeting protocols, including defined agendas and action-item documentation, enhance transparency and follow-through. Escalation pathways clarify when faculty intervention is required for methodological or boundary decisions. This governance structure reflects principle-based project management guidance emphasizing stewardship, accountability, and stakeholder alignment [4]. Within undergraduate research teams, explicit governance artifacts mitigate the coordination variability that often arises from informal collaboration patterns.

The delivery layer integrates milestone planning, Lean-inspired reliability mechanisms, and iterative learning cycles. A semester roadmap aligns research phases—literature review, protocol design, data collection, analysis, dissemination—with defined stage gates. Each stage gate requires artifact completion criteria (definition-of-done) to reduce late-stage ambiguity. Lean-inspired lookahead planning and constraint logging mechanisms adapted from the Last Planner System [7] identify dependencies and remove blockers before commitment cycles. Weekly commitment planning establishes short-interval task commitments and enables measurement of planned-versus-completed ratios. This reliability tracking supports flow stabilization and early detection of variability [6], [7]. Agile-inspired retrospectives and sprint reviews provide structured reflection and adaptive learning cycles [5]. These routines encourage teams to examine coordination effectiveness, constraint removal patterns, and sustainability articulation practices, thereby reinforcing iterative refinement.

The measurement and learning layer integrates workflow indicators, sustainability reasoning assessments, and reflective evaluation. Delivery reliability metrics (planned-versus-completed ratios, milestone adherence, revision histories) function as proxies for coordination discipline. Sustainability reasoning rubrics assess lifecycle boundary articulation, tradeoff documentation, and evidence-based justification. Reflection is structured rather than ad hoc. Retrospectives examine how governance artifacts influenced coordination, how sustainability checkpoints affected decision quality, and how constraint logs improved workflow stability. This alignment of performance measurement and reflection is consistent with experiential learning theory [8] and DBR evaluation principles [11]–[14].

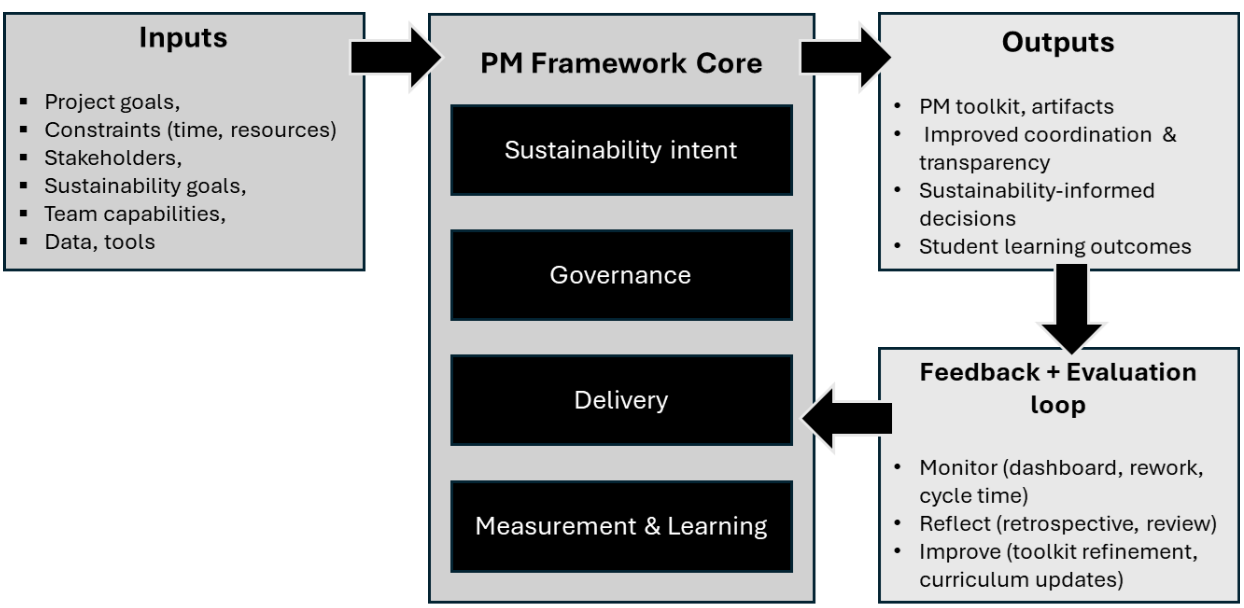

Figure 1. SRPD framework architecture (integrated layers, artifacts, routines, and feedback)

3.3 Integration Logic Across Layers

The layered architecture is not additive but interdependent. Sustainability checkpoints embedded within milestone gates connect the sustainability intent layer to the delivery layer. Governance artifacts ensure that sustainability responsibilities are assigned explicitly. Lean reliability metrics reinforce accountability for commitments that include sustainability-related tasks. Iterative retrospectives provide feedback loops linking measurement to refinement.

Table 1 clarifies that SRPD does not introduce new theoretical constructs; rather, it assembles established mechanisms from sustainable project management, Lean Construction, Agile methodologies, and principle-based governance into an operational architecture tailored to undergraduate research contexts. The functional contribution column emphasizes how each component addresses specific workflow vulnerabilities—such as coordination ambiguity, delayed constraint identification, or weak sustainability traceability—thereby reinforcing the integrated nature of the framework.

The integrated structure ensures that sustainability reasoning, coordination discipline, and iterative learning are enacted collectively rather than sequentially. By embedding sustainability considerations within recurring planning and evaluation routines, SRPD reduces the likelihood that sustainability remains peripheral to execution.

Table 1. SRPD elements and source frameworks

SRPD Component	Operational Artifact / Routine	Primary Theoretical Lineage	Functional Contribution in Research Workflow
Sustainability intent	SDG mapping; lifecycle boundary statement; sustainability decision log	Sustainable PM literature [2], [3]; UN SDGs [1]	Externalizes lifecycle scope and makes tradeoffs traceable during planning and execution
Governance and roles	RACI-style role map; meeting cadence; escalation rules	Principle-based PM governance [4]; cooperative learning structures [10]	Clarifies ownership, reduces coordination ambiguity, improves accountability
Milestone planning	Semester roadmap; stage gates; definition-of-done criteria	PM planning frameworks [4]; DBR iteration logic [11]–[14]	Aligns research phases with structured transitions; reduces late-stage variability
Lean reliability	Lookahead planning; constraint log; weekly commitment tracking	Lean Construction; Last Planner System [6], [7]	Stabilizes workflow cadence; enables early detection of dependency bottlenecks
Iterative learning	Sprint reviews; retrospectives; reflection prompts	Agile methods [5]; experiential learning [8]	Supports adaptive learning and continuous refinement of artifacts
Performance measurement	Delivery reliability metrics; sustainability rubric; revision history tracking	Evidence-based evaluation; sustainable PM measurement [2], [3]	Provides feedback loop linking governance routines to measurable outcomes

4. Research design and methodology

The Sustainable Research Project Delivery (SRPD) framework was developed and refined using a Design-Based Research (DBR) methodology. DBR is particularly appropriate for investigating complex educational interventions embedded within authentic contexts while generating transferable design principles [11]–[14]. Unlike controlled experimental approaches that isolate variables under laboratory conditions, DBR emphasizes iterative cycles of design, enactment, analysis, and refinement conducted within real-world constraints. The goal is both local improvement and theoretical contribution through systematic documentation of design decisions and mediating processes.

4.1 Context and Participants

Pilot implementations were conducted within faculty-led construction and infrastructure sustainability research projects over multiple 15-week academic semesters. Projects addressed built-environment themes including materials performance evaluation, infrastructure asset management, lifecycle energy assessment, and resilience-oriented design analysis. These topics required lifecycle reasoning, data interpretation, stakeholder consideration, and interdisciplinary coordination—conditions suitable for examining sustainability integration within structured delivery routines.

Teams consisted of three to six undergraduate students, primarily junior and senior level construction management or engineering majors. Faculty mentors retained methodological oversight and technical authority, including validation of sustainability boundary definitions, research design decisions, and final dissemination outputs. In some cases, external stakeholders provided contextual input or reviewed deliverables.

Students did not operate as independent principal investigators. Rather, they functioned as structured delivery integrators within supervised research systems. Their responsibilities included milestone planning, governance artifact maintenance, dashboard updates, constraint tracking, documentation of decision rationale, and facilitation of weekly commitment routines. Faculty retained responsibility for methodological rigor, data validity, and sustainability boundary appropriateness. This distribution of responsibility ensured research authenticity while enabling students to enact project management and sustainability integration mechanisms in a meaningful manner.

4.2 Iterative Development Through Design-Based Research

Consistent with DBR principles [11]–[14], the development of SRPD proceeded through iterative cycles characterized by needs analysis, prototype implementation, evaluation, and refinement. The process was not linear but recursive, with refinements triggered by observed workflow patterns and artifact analysis.

Baseline observations across early undergraduate research teams revealed recurring coordination inefficiencies. These included ambiguous task ownership, inconsistent meeting cadence, limited traceability of sustainability-related decisions, and late-stage revisions in literature syntheses and methodological drafts. Sustainability considerations were often present in final reports but weakly articulated in earlier planning artifacts. Artifact repository audits indicated frequent version revisions clustered near project deadlines, suggesting reactive rather than proactive workflow management. These observations informed the initial conceptualization of SRPD as an integration architecture linking governance discipline, delivery reliability mechanisms, and sustainability checkpoints.

The first iteration introduced structured governance artifacts, including RACI-style role maps, defined meeting agendas, and milestone-based planning aligned with research phases. Stage gates required artifact completion criteria prior to transition between phases. Early implementation improved ownership clarity but revealed persistent variability in sustainability articulation and constraint visibility.

Subsequent iterations incorporated additional mechanisms. Structured sustainability checkpoint templates were embedded within milestone reviews to require explicit articulation of lifecycle boundaries, indicator selection, and tradeoff documentation. Lean-inspired lookahead planning and constraint logs were introduced to identify dependencies and remove blockers prior to weekly commitment cycles.

Each refinement was informed by triangulated evidence. Repository analytics indicated whether revision patterns shifted earlier in the semester. Sustainability reasoning rubrics evaluated improvements in tradeoff articulation. Retrospective discussions provided qualitative insight into coordination dynamics. Faculty interviews assessed perceived changes in transparency and workflow stability. Rather than attributing observed improvements to isolated artifacts, analysis focused on relationships between integrated layers. For example, improvements in sustainability articulation were examined in relation to both checkpoint templates and governance routines that required explicit documentation during meetings.

4.3 Implementation fidelity

Ensuring implementation fidelity required balancing structure with flexibility. Core artifacts—including milestone roadmaps, role maps, sustainability logs, constraint registers, and weekly commitment dashboards—were designated as minimum viable components of the framework. Teams could adapt formatting and tool platforms (e.g., spreadsheet dashboards, shared document repositories), but core routines remained consistent: weekly commitment planning, milestone gate reviews, sustainability checkpoint documentation, and retrospective evaluation.

Faculty mentors monitored adherence to core routines while allowing contextual tailoring. Fidelity was assessed through artifact completeness audits, meeting metadata, and retrospective notes. Deviations from intended routines were documented and analyzed to inform subsequent refinements.

4.4 Data Collection and Analytical Framework

Evaluation employed a mixed-method approach integrating quantitative indicators and qualitative evidence streams. Delivery reliability was assessed through planned-versus-completed task ratios derived from weekly commitment logs. Milestone adherence was tracked through roadmap completion status. Revision histories and timestamp analysis of artifact repositories provided proxies for rework signals, including frequency of reopened tasks and clustering of revisions near deadlines. Role clarity and accountability were assessed through the percentage of tasks with explicitly named owners and through survey-based Likert-scale instruments evaluating perceived ownership transparency and meeting effectiveness.

Sustainability reasoning was evaluated using structured rubrics applied to literature reviews, methodological drafts, interim reports, and final dissemination products. Criteria assessed clarity of lifecycle boundary definition, articulation of tradeoffs, justification of selected sustainability indicators, and integration of environmental or social considerations within analytical reasoning. Rubric scoring was conducted by faculty mentors using consistent criteria across iterations. Changes in rubric patterns were examined longitudinally to identify directional trends.

Qualitative data included faculty interviews, student reflection prompts, and retrospective meeting notes. These data provided insight into perceived workflow stability, clarity of sustainability reasoning, and perceived usefulness of governance artifacts.

Quantitative indicators (e.g., planned vs. done, milestone adherence, artifact completion rates, revision counts, meeting efficiency metrics) were summarized descriptively and examined longitudinally within pilot teams. Given limited sample size, statistical inference was not emphasized; rather, analysis focused on directional patterns and consistency across contexts.

Qualitative data were analyzed through iterative thematic coding. Initial codes reflected SRPD design conjectures, including ownership clarity, constraint visibility, sustainability articulation, and feedback cycle frequency. Emergent themes were integrated into subsequent refinement cycles.

Triangulation across evidence streams strengthened interpretive validity. For example, improvements in role clarity were considered robust when survey responses, artifact audits, and faculty observations converged. **Table 2** summarizes the evaluation constructs, operational measures, evidence sources, and interpretation logic.

Table 2. Evaluation constructs, measures, and data sources

Construct	Operational measure	Data source(s)	Interpretation
Coordination / collaboration quality	Collaboration survey index (Likert); meeting agenda adherence; on-time action closure	Surveys; meeting minutes/metadata; observation notes	Higher values indicate improved coordination and communication discipline
Role clarity & accountability	Role clarity score; % tasks with named owner; RACI/role-card completeness	Surveys; artifact audits; dashboards	Higher clarity expected to reduce duplicated work and decision latency
Delivery reliability	Planned vs. completed tasks per week; milestone adherence	Weekly plan logs; milestone/progress dashboard	Higher reliability indicates stable workflow and effective planning control
Rework / iteration signals	Revision count per artifact; % reopened tasks; late change frequency; rework index	Repository logs; task board; issue logs	Lower rework suggests clearer requirements, better feedback loops, and improved DoD discipline
Sustainability integration / reasoning	Rubric score for lifecycle framing, tradeoff articulation, evidence use; checkpoint completion quality	Memos; decision logs; sustainability sheets; checkpoint reviews	Higher scores indicate stronger sustainability competence and decision traceability
Toolkit usability / adoption	Perceived usefulness; adoption friction; routine adherence	User feedback; retrospective notes; observation notes	Higher usability supports scalability and sustained implementation

5. Implementation Structure and Pilot Enactment

SRPD was implemented through a structured semester sequence aligned with a 15-week academic cycle. Rather than functioning as a standalone instructional module, the framework was embedded within ongoing faculty-led research projects, thereby situating sustainability reasoning and delivery discipline within authentic technical contexts.

The implementation model followed **five interconnected phases:** exploration and scoping; framework configuration; pilot enactment; evaluation and refinement; and dissemination with structured reflection. **Table 3** outlines the semester sequence and associated artifacts.

Table 3. Semester sequence and expected deliverables (15-week template)

Weeks	Phase focus	Student activities	Artifacts / outputs
1–3	Phase 1: Exploration & planning	Needs assessment & scoping; review research goals; map stakeholders; define sustainability targets and boundaries; set team norms	Project charter; SDG/TBL map; initial backlog; role map
4–6	Phase 2: Framework design	Toolkit tailoring & planning; develop milestone plan; pull-plan deliverables; define definition-of-done; set dashboard metrics	Semester roadmap; pull plan; constraint log; dashboard v1
7–10	Phase 3: Pilot implementation	Execution & data work; run weekly work planning; track constraints; conduct research tasks; hold sprint reviews	Work plans; decision log; meeting minutes; interim deliverables
11–13	Phase 4: Evaluation & optimization	Analysis & synthesis; integrate results; update sustainability claims with evidence; reduce rework via peer review	Analysis memos; updated dashboard; draft figures/tables
14–15	Phase 5: Wrap-up &dissemination	Dissemination & reflection; prepare paper/poster; conduct retrospective; propose improvements to toolkit	Final deliverable package; retrospective report; toolkit v2

During the **initial exploration phase** (Weeks 1–3), teams conducted structured needs assessments, reviewed research objectives, identified stakeholders, and defined preliminary sustainability boundaries. This stage culminated in a project charter, SDG or lifecycle mapping sheet, and initial backlog documentation. Explicit articulation of lifecycle boundaries at this stage reduced ambiguity regarding the scope of sustainability claims in later phases.

In the **framework configuration phase** (Weeks 4–6), teams developed milestone roadmaps aligned with research deliverables, constructed role maps clarifying task ownership, and established dashboard metrics for tracking delivery reliability and sustainability integration. Lean-inspired lookahead planning was introduced to identify foreseeable constraints, including data access limitations, scheduling conflicts, and methodological dependencies.

The **pilot enactment phase** (Weeks 7–10) represented the most intensive period of workflow activity. Weekly commitment planning sessions were conducted to define short-interval tasks and record planned-versus-completed ratios. Sustainability checkpoints were embedded within milestone reviews, requiring documentation of lifecycle tradeoffs and justification of indicator selection. Constraint logs were reviewed and updated regularly to prevent bottlenecks.

During the **evaluation and optimization phase** (Weeks 11–13), teams analyzed intermediate findings, conducted peer reviews of deliverables using definition-of-done criteria, and revised sustainability claims based on evidence gathered. Revision histories were examined to identify patterns of rework distribution. Retrospectives focused on identifying coordination breakdowns and assessing the effectiveness of governance artifacts.

The **final dissemination phase** (Weeks 14–15) involved preparation of conference papers, posters, or internal reports. Structured retrospectives documented perceived strengths and weaknesses of the framework. Teams proposed refinements to artifacts, contributing to subsequent DBR iterations.

Across pilot implementations, adherence to core routines—weekly commitment planning, milestone gates, sustainability checkpoint documentation, and retrospective reflection—remained consistent. Variations in tool format (e.g., spreadsheet dashboards versus shared online documents) were permitted, provided that core functional elements were preserved.

6. Preliminary results (pilot outcomes and mechanisms)

Preliminary findings from pilot implementations are presented below. Given the exploratory nature of DBR and limited sample sizes, results are interpreted as directional indicators supported by triangulated evidence rather than definitive causal claims.

6.1 Coordination Transparency and Role Clarity

Introduction of structured role maps and governance artifacts produced observable shifts in ownership clarity. Artifact audits indicated increased percentages of tasks with explicitly identified owners following the first implementation cycle. Faculty mentors reported fewer instances of duplicated effort and fewer ambiguous handoffs between team members.

Meeting metadata revealed improved agenda adherence and more consistent documentation of action items. Retrospective notes indicated that dashboards functioned as shared coordination anchors, reducing reliance on informal communication channels. Students reported greater clarity regarding expectations and accountability, particularly in later iterations when role definitions were reinforced at milestone transitions.

Qualitative analysis suggested that role clarity functioned as a mediating mechanism linking governance artifacts to delivery reliability. When ownership was explicitly documented, constraint identification occurred earlier and fewer tasks were reopened due to incomplete initial execution.

6.2 Delivery Reliability and Rework Distribution

Weekly commitment logs provided insight into delivery reliability patterns. Across multiple pilot teams, planned-versus-completed task ratios demonstrated stabilization over the course of the semester. Early weeks exhibited variability, but later phases showed more consistent adherence to commitments.

Repository revision histories revealed notable shifts in rework distribution. In initial iterations, revisions clustered near project deadlines, particularly for literature syntheses and methodological drafts. After introduction of structured definition-of-done checklists and milestone gates, revision activity was redistributed earlier in the semester. While total revision counts did not necessarily decline dramatically, the timing of revisions shifted to lower-cost stages, consistent with Lean principles emphasizing early detection of variability [6], [7].

Constraint logs facilitated earlier identification of dependencies, including data access delays and methodological uncertainties. Retrospective discussions frequently cited the lookahead planning routine as instrumental in preventing last-minute coordination crises.

6.3 Sustainability Integration and Lifecycle Articulation

Sustainability reasoning was evaluated through rubric scoring applied to written artifacts. Early pilot implementations exhibited variability in lifecycle boundary articulation and tradeoff documentation. Following introduction of structured sustainability checkpoint templates, rubric consistency improved. Students increasingly articulated which lifecycle stages were influenced by their research decisions and justified indicator selection with reference to stakeholder or environmental considerations.

Decision logs demonstrated increased documentation of sustainability-related tradeoffs during planning stages rather than solely in final reports. Faculty mentors noted that sustainability discussions became more frequent during milestone reviews when checkpoint prompts required explicit articulation.

Qualitative reflections indicated that embedding sustainability within recurring routines altered team discourse. Rather than treating sustainability as an abstract objective, teams began referencing lifecycle implications during methodological discussions. This shift suggests that operational embedding of sustainability checkpoints enhances salience during execution phases.

6.4 Toolkit Usability and Continuity Effects

Feedback indicated that artifact usability influenced adoption fidelity. When dashboards were streamlined and aligned with meeting cadence, adherence improved. Excessively complex templates reduced engagement. Subsequent iterations simplified visual representations while preserving core functionality.

An additional outcome was improved continuity across semesters. Structured documentation practices enabled new team members to understand prior decisions more efficiently. Faculty mentors reported reduced “restart costs” when transitioning between cohorts, suggesting that SRPD artifacts contribute to institutional memory within research groups.

7. Discussion and implications

The findings of this study suggest that sustainability integration in undergraduate construction research environments is not primarily constrained by conceptual awareness but by the absence of structured operational routines that connect sustainability intent to recurring delivery behaviors. The SRPD framework demonstrates how sustainability-oriented decision-making can be embedded within governance artifacts, milestone planning structures, and reliability tracking mechanisms without introducing a standalone sustainability module.

7.1 Operationalizing Sustainability Through Delivery Architecture

Sustainable project management scholarship emphasizes lifecycle thinking and governance transparency [2], [3]. However, the literature frequently addresses these dimensions at a conceptual or organizational level. The present study extends this body of work by specifying an operational translation layer tailored to undergraduate research workflows. By embedding sustainability checkpoints within milestone transitions and requiring documented tradeoff articulation in decision logs, SRPD links sustainability intent to routine execution practices.

The results indicate that sustainability reasoning improved when lifecycle boundaries and indicator justification were revisited at defined stage gates rather than deferred to final reporting. This suggests that sustainability becomes more actionable when integrated within governance routines that structure decision-making moments. In this sense, SRPD contributes a workflow-centric perspective to sustainable project management literature, demonstrating how established sustainability principles can be enacted through recurring coordination artifacts.

7.2 Lean Reliability and Knowledge-Intensive Workflows

Lean Construction mechanisms were originally developed for physical production systems characterized by variability and interdependency [6], [7]. This study suggests that similar variability patterns exist within knowledge-intensive research workflows. Late-stage revision clustering, delayed dependency recognition, and inconsistent task ownership mirror flow instability in production contexts.

The introduction of lookahead planning, constraint logging, and weekly commitment tracking appeared to stabilize workflow cadence. Redistribution of rework from late stages to earlier checkpoints is consistent with Lean principles emphasizing early variability detection [6]. While undergraduate research differs from construction production in material form, both contexts benefit from explicit visibility of dependencies and structured commitment discipline. These findings reinforce the broader applicability of Lean reliability mechanisms beyond construction sites and into research-based educational environments.

7.3 Governance Discipline and Educational Development

Principle-based governance frameworks emphasize stewardship, accountability, and value delivery [4]. In undergraduate research contexts, governance discipline is often informal and implicitly assumed. The introduction of structured role maps, decision logs, and meeting cadence protocols externalized accountability and reduced ambiguity in task ownership.

From an educational perspective, this structured governance may contribute to professional readiness. Students were not only learning sustainability theory but enacting governance mechanisms analogous to professional practice. Experiential learning theory suggests that structured reflection embedded within authentic tasks enhances knowledge construction [8]. By aligning governance routines with sustainability checkpoints, SRPD integrates experiential learning with professional delivery discipline.

7.4 Integration Rather Than Addition

A notable implication is that sustainability integration does not require curricular expansion through additional content modules. Instead, embedding sustainability reasoning within recurring project routines may be more effective than treating sustainability as a discrete instructional unit. This aligns with engineering education research emphasizing the value of integrating professional competencies within technical coursework rather than compartmentalizing them [9], [10].

The rating-system-agnostic design of SRPD enhances adaptability. By focusing on lifecycle reasoning and decision traceability rather than compliance with specific certification systems, the framework can be applied across diverse sustainability domains and research topics.

7.5 Scalability and Institutionalization

The continuity effects observed across semesters suggest potential institutional benefits. Structured artifacts and decision logs functioned as knowledge repositories that reduced restart costs when team composition changed. This may be particularly valuable in research labs with rotating undergraduate cohorts.

Scalability considerations include artifact complexity, faculty workload, and integration with existing curricular structures. Lightweight dashboards and clearly defined core routines were associated with higher adoption fidelity. Future implementations may explore modular adaptations tailored to capstone courses, competition teams, or research apprenticeship models.

7.6 Limitations and Future Research

Several limitations should be acknowledged. First, pilot implementations occurred within a limited number of research contexts and involved relatively small team sizes. While triangulated evidence supports directional findings, statistical generalization is not warranted. Second, some performance indicators—such as revision counts and task completion ratios—function as proxies rather than direct measures of learning or sustainability impact. Third, faculty involvement varied across projects, potentially influencing outcomes.

Future research should expand implementation across multiple institutions and compare teams using SRPD with control groups employing conventional research coordination structures. Longitudinal studies could examine whether participation in SRPD influences subsequent capstone performance or professional practice. Validation of sustainability reasoning rubrics through inter-rater reliability analysis would strengthen measurement robustness.

Further exploration of digital tool integration, including automation of dashboard metrics and constraint tracking, may enhance scalability. Additionally, examining how SRPD interacts with interdisciplinary teams could provide insight into broader applicability beyond construction-focused contexts.

8. Conclusion and future work

This study presented the Sustainable Research Project Delivery framework as an operational integration architecture for embedding sustainable project management mechanisms within undergraduate construction research workflows. Drawing upon established traditions in sustainable PM [2], [3], Lean Construction [6], [7], Agile methodologies [5], principle-based governance [4], and experiential learning [8], SRPD assembles complementary mechanisms into a layered system of governance artifacts, milestone structures, sustainability checkpoints, and reliability metrics.

Developed and refined through Design-Based Research cycles in authentic faculty-led sustainability projects, SRPD demonstrates potential to improve coordination transparency, commitment reliability, rework distribution patterns, and lifecycle-based sustainability articulation in student deliverables. The contribution lies not in redefining sustainability constructs, but in specifying how existing frameworks can be enacted through structured routines within semester-bounded research environments.

By aligning professional delivery mechanisms with undergraduate research practice, SRPD offers a replicable model for integrating sustainability and project management competencies within construction engineering education. Future research will expand pilot contexts, refine measurement instruments, and examine long-term impacts on professional readiness and sustainability-oriented decision-making.

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