Integrating the Project Life Cycle and the Six Constraints for Sustainable Environmental Project Management: A Conceptual Synthesis with a Comparative Case Illustration

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ABSTRACT

Environmental projects are delivered under the same generic project life cycle and six-constraint structure (time, cost, scope, quality, resources and risk) used across the project management discipline, but sustainability requirements change what each phase and each constraint must accomplish. This paper synthesises peer-reviewed project management and sustainability-accounting literature to examine how the initiation, planning, execution/monitoring and closing phases interact with the six constraints when a project must deliver measurable environmental outcomes alongside the United Nations Sustainable Development Goals (SDGs). It argues that quality and risk cannot be managed as residual constraints once time, cost and scope are fixed, because ecological outcomes and deep uncertainty need to be built into the project definition from initiation onward. The argument is illustrated against two documented combined-sewer-overflow interception programmes: the Thames Tideway Tunnel, a £4.6 billion, 25 km project in London, and the DC Clean Rivers Project, a US$2.7 billion multi-tunnel programme in Washington, D.C. Comparing a UK scheme driven by an EU-derived regulatory settlement with a US scheme driven by a federal consent decree shows the framework's constraint interactions recurring under two different governance triggers and two different life-cycle stages, one substantially complete and one still under construction. An illustrative phase-by-constraint-by-SDG mapping is proposed as a planning heuristic. The paper draws its argument from published literature and two documented cases rather than from primary data collection or a statistically representative sample, and its claims should be read accordingly.

General Terms

Project Management, Sustainability, Infrastructure Delivery.

Keywords

Environmental project management, project life cycle, project constraints, sustainable development goals, risk management, sustainability accounting, Thames Tideway Tunnel, DC Clean Rivers Project.

1. INTRODUCTION

A project is conventionally defined as a temporary endeavour undertaken to create a unique product, service or result, bounded by a defined start and end [1]. In environmental management practice, a project additionally functions as the delivery mechanism for sustainability commitments and regulatory obligations, so success cannot be assessed on schedule and budget performance alone. Two frameworks are used throughout the discipline to structure this delivery: the project life cycle, which sequences work into initiation, planning, execution/monitoring and closing phases, and the six constraints of time, cost, scope, quality, resources and risk, which bound what a project can achieve within that sequence.

This paper synthesises how these two frameworks apply to environmental projects that are required to contribute to the 2030 Agenda for Sustainable Development [9]. It draws on published project management and sustainability-accounting research, and on two documented cases rather than on original data collection: Section 5 examines the Thames Tideway Tunnel, a London sewer-overflow interception project reported in a 2025 special issue of the Proceedings of the Institution of Civil Engineers [10] and in two National Audit Office reviews [11], [12]. Section 6 adds a second, independently documented scenario, the DC Clean Rivers Project in Washington, D.C. [14], [15], [16], so that the framework is evaluated against two infrastructure programmes with different regulatory triggers, delivery structures and life-cycle stages rather than a single instance. Where the underlying literature reports mixed or partial evidence, the paper says so explicitly rather than presenting a uniformly confident account.

2. THE PROJECT LIFE CYCLE IN ENVIRONMENTAL PROJECTS

2.1 Initiation

Turner and Müller [1] analyse the project as a temporary organisation created to manage change, allocate resources and absorb uncertainty on behalf of a permanent parent organisation. Read against this view, weak initiation is not a localised problem: because the temporary organisation inherits its objectives and resourcing decisions from this phase, gaps left here propagate into planning and execution rather than being corrected independently later. For environmental projects, initiation is where project objectives must be linked to specific SDG targets; Gareis et al. [2], in a Project Management Institute-sponsored study of sustainable development in project practice, argue that sustainability principles need to be built into a project's initiation and structuring rather than added once delivery is under way.

2.2 Planning

Planning is where sustainability intentions set at initiation are converted into scoped, resourced and scheduled work packages. Carvalho and Rabechini [3], in a survey-based study of 111 projects, report a positive and statistically significant relationship

between project sustainability management and both social and environmental performance, which supports treating sustainability planning as a determinant of delivered outcomes rather than an add-on. Staged development processes such as the RIBA Plan of Work [4], which structures design and construction projects into progressively more detailed stages, offer one practical mechanism for carrying environmental requirements through increasing levels of technical detail without them being diluted as designs are finalised.

2.3 Execution, monitoring and control

During execution, the planned approach meets site and stakeholder realities that were not fully knowable at the planning stage. Hörisch, Schaltegger and Freeman [5] synthesise stakeholder theory with sustainability accounting and argue that which stakeholders and which sustainability topics an organisation accounts for jointly determine what is monitored and reported during delivery. Applied to project control, this implies that the monitoring indicators fixed at planning stage need to be revisited as new stakeholder concerns or ecological information emerge during execution, rather than treated as fixed once set.

2.4 Closing

Müller, Drouin and Sankaran [6] propose a seven-layer model of organisational project management that links individual project governance to portfolio- and organisation-level decision-making. Applied to closure, this suggests that lessons captured at project end are only useful if a governance layer exists to feed them into future project selection and design; for environmental projects this includes post-implementation monitoring to verify that claimed ecological benefits actually materialised, since the SDG contribution of a project can typically only be confirmed after handover, not at completion.

3. RECONCEPTUALISING THE SIX CONSTRAINTS

Serrador and Turner [7], analysing a survey of 1,386 projects, report that meeting time, cost and scope targets (project efficiency) correlates only moderately with overall project success ($r = 0.60$, $R^2 = 0.36$), and that broader measures, including stakeholder satisfaction, account for the remainder. This is direct empirical evidence, not an assumption, that the time-cost-scope triangle is an incomplete success criterion, which motivates treating quality, resources and risk as equally load-bearing constraints rather than residual ones.

Quality: for an environmental project, a deliverable that is completed on time and within budget but fails to meet its stated ecological performance targets has not met its quality requirement, regardless of schedule and cost performance. Carvalho and Rabechini's finding that sustainability management is associated with environmental as well as social performance outcomes [3] supports defining quality in these projects to include ecological performance, particularly where the project is intended to contribute to SDG 9 (industry, innovation and infrastructure) or SDG 11 (sustainable cities and communities).

Risk: Aven [8] distinguishes ordinary probabilistic risk from deep uncertainty, where the possible outcomes or their likelihoods cannot be fully specified in advance, and argues that deep uncertainty requires adaptive management strategies rather than a single predetermined risk response plan. Ecological systems frequently present this kind of uncertainty, which is relevant to projects addressing SDG 13 (climate action) or SDG 15 (life on land), where the ecological response to an intervention may not be fully known when risk is first assessed. Section 6.3 presents a second, independent instance of this dynamic.

Resources: resources in an environmental project extend beyond budget and labour to specialised ecological expertise and stakeholder relationships. Hörisch, Schaltegger and Freeman's synthesis of stakeholder theory [5] treats the identification and inclusion of relevant stakeholders as a condition for effective sustainability accounting, which supports treating stakeholder-engagement capacity as a resource constraint in its own right rather than a communications task that sits outside the resourcing plan.

These four constraints do not operate independently. Carvalho and Rabechini [3] observe that investment in higher environmental quality can raise upfront cost while reducing long-term risk exposure, which is a cost-quality-risk trade-off rather than a simple cost increase; treating it only as a cost overrun, without accounting for the associated risk reduction, misrepresents the decision.

4. MAPPING PHASES, CONSTRAINTS AND SDG LINKAGES

Table 1 proposes an illustrative mapping of dominant constraint trade-offs and plausible SDG linkages against each life-cycle phase. This mapping is the authors' own synthesis, intended as a planning heuristic to prompt discussion during project scoping. It is illustrated, but not statistically validated, against the two cases examined in Sections 5 and 6.

Table 1. SDG linkage and constraint mapping across the project life cycle (authors' synthesis)

Phase	SDG linkage	Dominant constraint trade-off
Initiation	6, 9, 11, 13, 17	Scope-resources: balancing ambition against feasibility; cost-quality: cost of early stakeholder and uncertainty analysis
Planning	6, 9, 11, 12	Cost-quality: premium for sustainable technology and delivery structure versus long-term savings; time-resources: allocation for impact assessment
Execution / control	6, 9, 11, 14, 15	Quality-time: environmental safeguards against schedule pressure; scope-risk: adaptive response to emergent conditions
Closing	6, 9, 11	Resource-quality: funding long-term monitoring; time-scope: allowing adequate evaluation periods before handover

5. CASE ILLUSTRATION: THE THAMES TIDEWAY TUNNEL

The Thames Tideway Tunnel is a 25 km deep-level tunnel running from Acton to Abbey Mills in London, built to intercept 34 combined sewer overflows and prevent untreated sewage from discharging into the tidal River Thames [10]. It is used here as a documented illustration of the framework in Sections 2 to 4 because it is one of the few environmental infrastructure projects with a full, publicly reported life-cycle record, spanning a 2025

special issue of Proceedings of the Institution of Civil Engineers devoted entirely to the scheme [10] and two National Audit Office reviews of its value for money [11], [12]. The account below is drawn entirely from these secondary, documentary sources; no primary data were collected for this paper, and the mapping to Table 1 is illustrative rather than a claim that the project's delivery team used this framework.

5.1 Life-cycle timeline

Initiation ran from 2000 to 2014, an unusually long span for this phase. Thames Water began feasibility research in 2000, prompted by a 1991 EU Directive requiring member states to control urban wastewater discharges; the research reported in 2005, and the UK government announced support for a full-length tunnel as the preferred solution in 2007 [11]. The Court of Justice of the European Union found the UK in breach of the Directive in 2012, and it took the Department for Environment, Food and Rural Affairs (Defra) and the Environment Agency until 2010 to agree measurable environmental standards for the scheme, with a third strategic objective, securing sufficient sewer capacity for London's growth, added as late as 2014 [11]. The 2017 NAO review found that the hydraulic models used to rule out smaller alternatives to the full tunnel had not been fully tested for uncertainty before that decision was made [12], which is consistent with this paper's claim in Section 2.1 that gaps left at initiation are not easily corrected later: by the time the modelling concern was raised, the scope and cost baseline had already been fixed.

Planning and delivery-model design (2013-2015) established a special-purpose, Ofwat-regulated infrastructure provider, Bazalgette Tunnel Limited ('Tideway'), separate from Thames Water, under the 2013 Specified Infrastructure Projects Regulations [10]. This is a concrete instance of the planning-phase governance point made in Section 2.2: the delivery structure itself, not only the technical design, was treated as something to be engineered before construction began.

Execution ran from 2016, when construction began at multiple sites, to substantial completion of tunnelling in 2024 [10]. The COVID-19 pandemic paused site works and added roughly nine months to the schedule and £233 million to the cost, an example of the deep uncertainty described by Aven [8]: a risk that could not have been specified in the original risk register. During 2024, groundwater infiltration was identified in some tunnel sections; it was investigated and found not to compromise structural integrity, and monitoring continued through commissioning [13], illustrating the execution-phase revisiting of monitoring indicators discussed in Section 2.3.

Closing has extended well beyond substantial construction completion. First sewage flows were diverted into the tunnel in 2024, the system was reported fully operational in August 2025, and operational handover to Thames Water was, at the time of the most recent published account, planned for early 2026, contingent on weather conditions permitting completion of storm testing [10]. This matches the closing-phase argument in Section 2.4 that an environmental project's ecological performance, here, verified overflow capture during real storm events, can only be confirmed after construction ends, not at the point of handover.

5.2 Constraint trade-offs observed

Cost grew from a regulatory baseline of £3.5 billion to a reported £4.6 billion at substantial completion [10], with earlier NAO reviews recording intermediate estimates of £4.2 billion in 2017 [12] and a government contingent-support exposure estimated at up to £6.6 billion in a reasonable-worst-case scenario [12]. The overspend beyond the regulatory baseline is shared, with Tideway bearing 40% and customers 60% [10], which is a documented risk-sharing mechanism rather than a simple cost overrun. Time was extended by approximately nine months due to the pandemic, on top of an original 2016-2024 construction window that itself followed 16 years of initiation and planning [10], [11]. Quality was defined operationally as intercepting substantially all combined sewer overflow events rather than as adherence to the original construction programme, consistent with the quality redefinition argued for in Section 3. Resources extended beyond the estimated 25,000 people who worked on the project since 2000 [10] to a formal stakeholder-resourcing mechanism: approximately 1,800 compensation claims from affected residents, valued at roughly £6 million in total, were assessed through an Independent Complaints Procedure and an Independent Complaints Commissioner [10], supporting the treatment of stakeholder-engagement capacity as a resource constraint set out in Section 3.

5.3 SDG linkage

The SDGs post-date the project's 2000 initiation, so the linkage discussed here is retrospective rather than a claim that the delivery team designed to the SDGs from the outset. The 2025 engineering-literature account of the project explicitly frames it against UN SDG 6 (clean water and sanitation), SDG 9 (industry, innovation and infrastructure) and SDG 11 (sustainable cities and communities) [10], which corresponds closely to the initiation- and planning-phase SDG linkages proposed in Table 1. The finer, phase-by-phase SDG granularity in Table 1 beyond these three goals remains this paper's own heuristic and has not been independently verified against either case.

6. COMPARATIVE SCENARIO: THE DC CLEAN RIVERS PROJECT

A single case cannot show whether the phase-constraint interactions argued for in Sections 2 to 4 are specific to one regulatory and institutional setting. This section adds a second, independently documented combined-sewer-overflow programme, DC Water's Clean Rivers Project in Washington, D.C., evaluated against the same four life-cycle phases and the same six constraints, using only verified secondary sources [14], [15], [16]. The two programmes address the same underlying engineering problem, intercepting combined sewer overflows with large bored tunnels, but differ in the trigger that started them, in delivery governance, and in life-cycle stage, which is what makes the comparison informative rather than repetitive.

6.1 Programme overview and governance trigger

Where the Thames Tideway Tunnel's initiation traces to a 1991 EU Directive and a negotiated settlement between Defra, the Environment Agency and Thames Water [11], the Clean Rivers Project's initiation traces to a 2005 consent decree under the US Clean Water Act, agreed between DC Water, the District of Columbia, the US Environmental Protection Agency and the US Department of Justice [14]. Both are regulatory-compliance projects rather than discretionary investments, but one originates in a supranational directive implemented through domestic agencies, and the other in direct federal litigation enforcement; this is a difference in the initiation-phase governance structure described in Section 2.1, not merely a difference of country. The programme's long-term control plan commits DC Water to a system-wide 96% reduction in combined sewer overflow volume [15], delivered through a package of large tunnels (the Anacostia River Tunnel, the Blue Plains Tunnel, the First Street Tunnel and the Potomac River Tunnel) supplemented, after a 2016 decree modification, by green infrastructure in part of the Rock Creek

sewershed [15]. Total programme cost is reported at approximately US$2.7 billion [15].

6.2 Life-cycle timeline and current status

Unlike the Thames Tideway Tunnel, which was delivered as one integrated construction programme, the Clean Rivers Project is a staged portfolio of separately phased tunnels under one consent decree, so its phases overlap across components rather than running once in sequence. The Anacostia River Tunnel, 2.4 miles (approximately 12,500 feet) long with a 23-foot diameter, was mined between October 2015 and November 2016 and entered service in March 2018 alongside the Blue Plains Tunnel, after which DC Water reports a 90% reduction in combined sewer overflows to the Anacostia River [15], [16]. The First Street Tunnel, a storage component, was brought into service under the original plan horizon. The Potomac River Tunnel, a separate 5.5-mile bored tunnel projected to cut overflows at that outfall from approximately 74 events a year to about 4 (a 93% reduction), was still in the excavation stage as of July 2025, with major drilling beginning near the Watergate site that month [17]. At the time of the most recently available published account, the programme as a whole therefore spans an execution phase that is substantially complete for one tunnel (Anacostia) and still active for another (Potomac), inside a single consent-decree initiation that is now two decades old.

6.3 Constraint trade-offs and the 2016 adaptive-scope revision

The clearest cross-case parallel is in the risk constraint discussed in Section 3. The Thames Tideway Tunnel absorbed an unplanned, deep-uncertainty disruption, the COVID-19 pandemic, through a schedule extension and a shared cost overrun [10]. The Clean Rivers Project shows a different but structurally similar adaptive response: in 2016, the consent decree itself was formally modified to allow green infrastructure to substitute for part of the originally specified grey infrastructure in the Rock Creek sewershed, in exchange for an extended compliance deadline for that portion of the programme [15]. In both cases, a fixed delivery plan agreed at initiation was revised once new information, a pandemic in one case, performance evidence on green infrastructure in the other, emerged during execution, which is consistent with Aven's argument [8] that deep uncertainty requires an adaptive management capability built into the project rather than a single fixed risk plan carried unchanged from initiation to closure. The two cases differ, however, in who could authorise that adaptation: Tideway's cost-sharing adjustment was a contractual mechanism between the regulated entity and its customers [10], while the Clean Rivers Project's scope substitution required renegotiating a federal court consent decree [15], a materially higher-friction route that plausibly explains why DC Water's adaptation targeted one sewershed rather than the whole programme. Quality, defined as achieved overflow reduction rather than adherence to the original all-grey-infrastructure design, is reported quantitatively for the Anacostia Tunnel (90% reduction, in service) and only as a target for the Potomac River Tunnel (93% reduction projected, under construction) [15], [16], [17], which illustrates the closing-phase point made in Section 2.4 that ecological performance claims are verified after handover and not before it: the Anacostia figure is a realised result, and the Potomac figure is still a plan commitment.

Table 2. Side-by-side comparison of the two documented cases

Dimension	Thames Tideway Tunnel (UK)	DC Clean Rivers Project (US)
Initiation trigger	EU Urban Waste Water Treatment Directive (1991); negotiated UK settlement, 2000-2014 [11]	US Clean Water Act consent decree, EPA/DOJ/DC Water/District of Columbia, 2005 [14]
Delivery structure	Single integrated tunnel; dedicated regulated infrastructure provider (Tideway) [10]	Portfolio of separately phased tunnels under one utility (DC Water) and one decree [15]
Reported cost	£3.5bn baseline to £4.6bn at substantial completion [10]	~US$2.7bn programme-wide, multiple tunnels and green infrastructure [15]
Execution status	Substantial completion 2024; handover pending storm testing [10]	Anacostia Tunnel in service since 2018; Potomac River Tunnel under construction, 2025 [16],[17]
Adaptive-scope event	Pandemic-driven 9-month extension; cost shared 40/60 [10]	2016 decree modification substituting green infrastructure in part of programme [15]
Verified outcome to date	Operational, pending confirmed storm-event capture [10]	90% CSO reduction to Anacostia River confirmed post-handover [16]

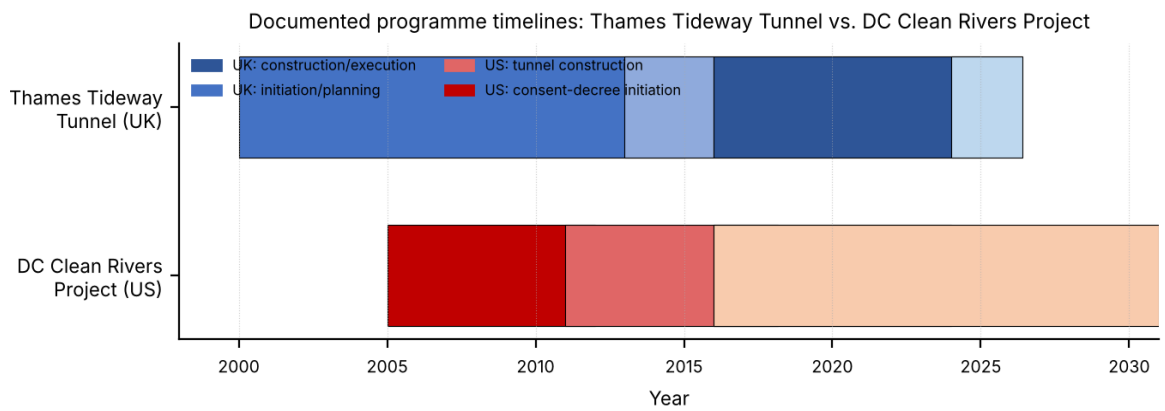


Fig 1: Documented programme timelines, Thames Tideway Tunnel and DC Clean Rivers Project (sources: [10], [11], [12], [15], [16], [17])

7. DISCUSSION

Read together, the sources reviewed in Sections 2 to 4, and the two cases in Sections 5 and 6, suggest a shift in how the six constraints should be sequenced for environmental projects: from a model where quality and risk are checked once time, cost and scope are fixed, to one where quality (ecological performance) and risk (deep uncertainty) are set at initiation and then used to bound the achievable scope, cost and schedule. The Thames Tideway case supports this at one specific point: the NAO's finding that hydraulic modelling uncertainty was not fully tested before the full-tunnel option was locked in [12] shows a risk-assessment gap at initiation that could not be cheaply corrected once construction was under way. The DC Clean Rivers case adds a second, independent data point for the risk argument rather than repeating it: the 2016 consent-decree modification shows that even a legally binding, court-enforced delivery plan was reopened once monitoring evidence on green infrastructure performance became available, which is the adaptive-management response Aven's framework [8] predicts for genuine deep uncertainty, observed here in a different country, a different regulatory instrument and a different decade of the programme.

The comparison also qualifies the earlier case-based claim rather than simply reinforcing it. Both schemes show quality defined as achieved environmental performance, but the two reported figures sit at different levels of evidential weight: the Thames Tideway Tunnel's overflow-interception performance has not yet been confirmed through a full storm-testing cycle at the time of the most recent published account [10], while DC Water's 90% reduction figure for the Anacostia River is a post-handover, already-realised result [16]. Treating both as equally confirmed would overstate the UK case; the paper is explicit here that only the US figure currently has that evidential status, while the UK figure remains a plan commitment pending verification, consistent with the closing-phase argument in Section 2.4 that ecological claims can only be confirmed after handover.

On governance, the two programmes also diverge in a way that bears on resourcing and risk. Thames Tideway's adaptation to the pandemic disruption was negotiated contractually between a regulated infrastructure provider and its economic regulator [10], a relatively fast mechanism. The Clean Rivers Project's adaptation required reopening a federal consent decree [15], a slower, judicially supervised process. This suggests that the resource constraint discussed in Section 3, stakeholder-engagement and governance capacity, should be read to include the institutional speed with which a delivery plan can be revised once deep uncertainty is recognised, not only the budget and staffing available to execute the plan as originally agreed; this is a refinement to the resource-constraint argument rather than a claim that was already available before examining both cases.

8. LIMITATIONS

This paper synthesises a limited set of published sources rather than conducting a systematic literature review, and the two cases in Sections 5 and 6 are drawn entirely from secondary, documentary sources, engineering-literature special issues, government audit reports and the delivering utilities' own published accounts, not from interviews, site access or primary project records. Two cases, however well documented, cannot establish that the proposed sequencing of quality and risk generalises across environmental project types, sizes or regulatory regimes; both the Thames Tideway Tunnel and the Clean Rivers Project are large, well-funded, single-country combined-sewer-overflow infrastructure programmes, so the comparison strengthens the risk-sequencing argument specifically for this project type without establishing it for smaller or differently regulated environmental projects, such as nature-based restoration schemes or community-scale retrofitting programmes. The SDG-constraint mapping in Table 1 remains illustrative outside the three goals explicitly confirmed in the Thames Tideway case literature and has not been independently confirmed against the DC Clean Rivers Project. The DC case is also reported from sources with different publication dates (2015-2025), so the Potomac River Tunnel figures reported in Section 6.2 describe a project still under construction at the time of writing and may change before completion. Testing the framework against a comparative set of environmental projects outside the combined-sewer-overflow category, ideally including cases where full-cycle governance failed rather than succeeded, remains a direction for further work rather than a claim already substantiated by this paper.

9. CONCLUSION

The project life cycle and the six constraints remain the structural tools through which environmental projects are delivered, but the evidence reviewed here, including the Thames Tideway Tunnel and DC Clean Rivers Project cases, indicates that treating quality and risk as constraints to be checked after time, cost and scope are agreed understates their role in environmental outcomes. Setting ecological quality criteria and acknowledging deep uncertainty at initiation, rather than at execution, is the more defensible sequencing based on the sources reviewed, and the recurrence of an adaptive-scope response to new evidence in two independently governed programmes strengthens that conclusion beyond what either case alone would support. Three directions follow from this: testing the phase-constraint-SDG mapping proposed in Table 1 against a larger comparative set of completed environmental project cases rather than the two examined here; measuring, rather than assuming, the cost-risk trade-off associated with higher environmental quality specifications reported qualitatively by Carvalho and Rabechini [3]; and developing governance mechanisms, building on Müller, Drouin and Sankaran's organisational model [6] and on the Tideway and Clean Rivers delivery-vehicle precedents [10], [15], that carry post-closure ecological monitoring data back into the selection and design of future projects.

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