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Front End Engineering Design Maturity and Investment Decision Quality in Public Infrastructure

A State-of-the-Art Review and an Integrated Framework for Uganda

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ABSTRACT
Front end engineering design (FEED) establishes the technical and commercial evidence on which capital investment decisions depend, yet its maturity is frequently treated as equivalent to document completion. This state-of-the-art review examines how FEED maturity, accuracy and quality relate to final investment decision (FID) effectiveness and public infrastructure performance, with particular attention to Uganda. A critical narrative synthesis was developed a targeted verification of peer reviewed research, Construction Industry Institute resources and Ugandan public investment sources. The evidence distinguishes deliverable development from confidence in its underlying assumptions, and identifies investment governance as the mechanism through which front end information can influence execution. Industrial project studies associate stronger FEED with improved cost performance, but their observational designs and potentially overlapping samples limit causal and cross sector inference. Infrastructure definition tools, project validation, external benchmarking and sustainability assessment provide complementary decision support. The review identifies unresolved problems in measuring FID effectiveness, transferring industrial instruments to public infrastructure, separating readiness from organizational capacity and assessing long term public value. An integrated framework is proposed that combines sector specific scope definition, independent assurance, stakeholder and safeguard readiness, affordability and documented approval conditions. It treats governance and external uncertainty as contextual influences and includes feedback from operations into future project preparation. The framework is a research proposition rather than an empirically validated Ugandan model. Longitudinal project records and independently verified baselines are needed to test its explanatory value and calibrate approval thresholds.

KEYWORDS: Front end engineering design; FEED maturity; Final investment decision; Public infrastructure; Project definition; Investment, Governance.

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I. INTRODUCTION

Public infrastructure decisions commit scarce resources before all engineering, commercial and institutional uncertainties can be resolved. The practical question is therefore not whether a project is fully designed, but whether the evidence available is sufficient for the particular commitment being authorized. FEED maturity research provides a basis for examining that question [1], while infrastructure scope definition tools connect planning assessments to the coordination of transport, utility and service networks [2]. Investment approval is especially consequential where subsequent redesign affects public budgets, land acquisition, operating expenditure and essential services.

FEED as an input to FID effectiveness and subsequent cost, schedule, scope and quality performance. This review advances that proposition into a distinct scholarly contribution: an assessment of what existing approaches measure, how they support decisions and where their use in Ugandan public infrastructure requires adaptation. It does not report the proposal's planned questionnaires, interviews or case studies as completed research. The manuscript also avoids treating all nationally significant projects as publicly funded; public sponsorship, regulation, state equity participation and private financing represent different governance arrangements.

The review asks three questions. First, how should FEED maturity, completeness, quality and accuracy be distinguished? Second, what does the available evidence establish about their relationship with investment decisions and project outcomes? Third, what integrated assessment and research approach is appropriate for

Uganda? The contribution is an explicit separation of technical readiness from decision quality, together with a proposed assurance framework that preserves sector differences and includes public value.

II. REVIEW APPROACH AND EVIDENCE BOUNDARIES

A critical narrative review was used because the objective is conceptual integration and appraisal of measurement approaches, rather than estimation of a pooled intervention effect. The literature review was not treated as empirical evidence of Ugandan project outcomes.

Targeted web searches on the front-end engineering design with maturity, accuracy, project performance and phase gate approval; front end planning with infrastructure and PDRI; and Uganda with public investment management and project preparation. Publisher pages, university research repositories, CII resources and Ministry of Finance sources were prioritized. Foundational studies were retained alongside relevant developments published through 2025. This was not an exhaustive database search, and no claim of complete coverage of 2026 publications is made.

Sources were selected for direct relevance to front end definition, authorization decisions, project assurance, sustainability or Ugandan investment institutions. For each core contribution, the synthesis considered its construct, evidence type, project context, principal finding and transfer limitation. Article metadata and accessible abstracts or full texts were checked where available. Abstract only access restricts assessment of detailed sampling, confounding and statistical procedures; numerical claims were therefore confined to explicitly reported findings.

The review is purposive and source bounded. It has no registered protocol, exhaustive screening count, duplicate reviewer assessment or PRISMA flow diagram. Its findings should be read as a critical synthesis of selected evidence, not a systematic review or meta-analysis. Direct empirical FEED evidence is distinguished below from complementary frameworks and from this paper's own proposed analytical deductions.

III. CONCEPTUAL DISTINCTIONS IN FRONT END PROJECT DEVELOPMENT

Front end planning is the broader process of defining the need, exploring alternatives, assessing feasibility and developing the scope and execution basis. FEED is the engineering intensive component that develops a selected concept sufficiently for appraisal and subsequent design. Front end loading describes the effort invested before execution. These terms overlap in practice but should not be assumed to have identical boundaries. For roads, water systems or transmission networks, an equivalent readiness package may exist without a formally named FEED contract.

Completeness concerns whether required deliverables exist and cover their intended scope. Maturity concerns how far the technical definition has developed. Quality concerns fitness for purpose, internal consistency, compliance with agreed requirements and the adequacy of review. Accuracy, as operationalized by Gibson and colleagues [3], concerns confidence in the assessed maturity and the environment supporting the engineering work. It should not be reduced to the difference between a forecast and its eventual realized value. A complete document set can contain immature interfaces or unreliable assumptions, while a credible early estimate can correctly disclose substantial uncertainty.

FID is the formal authorization to commit capital to execution. In public infrastructure, its functional equivalent may involve several approvals rather than a single corporate sanction. Project appraisal approval, budget inclusion, borrowing authorization, contract award and financial closure should therefore be recorded separately. Decision effectiveness concerns the adequacy, traceability and appropriate use of evidence at the relevant commitment point. Approval speed or sponsor confidence alone cannot establish decision quality.

Cost estimate classification should follow the relevant sector guidance and estimate basis. The proposal's blanket precision range for FEED is not retained: confidence depends on scope definition, data quality, market conditions, contingency and risk exposure. A stated estimate class cannot substitute for an explicit uncertainty assessment. Detailed engineering design likewise remains a later process that develops construction and procurement information; sufficient investment readiness does not imply that every construction detail is resolved.

IV. A STATE OF THE ART IN FEED ASSESSMENT AND DECISION SUPPORT

4.1 Deliverable maturity and scope definition

Yussef et-al [1] developed a FEED maturity assessment using 33 completed large industrial projects with a combined installed cost exceeding USD 8.83 billion. The authors reported a 20 percent difference in cost growth relative to the approved budget between high and low maturity groups. This supports a measurable association between front end definition and cost performance. It does not establish a universal saving, an effect for every infrastructure sector or a causal estimate applicable to Uganda.

CII's infrastructure PDRI [2] assesses scope definition and supports collaborative review. Its reported validation distinguishes projects scoring below and above 200 before detailed design and construction. Lower scores indicate better definition. Repeated assessments are encouraged because understanding of unresolved

issues changes during planning. The score is therefore a diagnostic aid rather than an automatic authorization rule. Its historical threshold should not be transferred into Ugandan sector approval requirements without calibration.

An important implication is that a total score must be accompanied by an issue profile. Strong definition in routine disciplines can conceal a critical unresolved adventure, water source, land parcel or utility interface. Investment readiness is partly non compensatory: some omissions cannot be offset by excellent documentation elsewhere.

4.2 Accuracy and organizational assurance

Gibson et-al [3] identify 27 FEED accuracy factors concerning leadership, execution teams, management processes and resources. Their analysis also used 33 large industrial projects worth USD 8.8 billion and reported stronger cost growth performance for high accuracy projects. Accuracy complements maturity by asking whether decision makers can trust the assessment of the engineering package. Because the author's sample sizes and aggregate project values overlap with the maturity research, these publications should not be counted as independent replications without checking the underlying datasets.

The conceptual advance creates a measurement challenge. If organizational capability is included within FEED accuracy and also treated as a moderator, the same information may appear on both sides of an explanatory model. A study should define construct boundaries before estimating relationships. Technical deliverable maturity can be measured from dated documents; assurance credibility from review origin and verification; and organizational capability from staffing, resources and decision authority. Separating these observations makes the proposed mechanism easier to test.

4.3 Validation and the control of optimistic assumptions

Project validation research [4] considers set based and concurrent design as a way to inform owner authorization during conceptual development. Its relevance is that alternatives can be tested before a preferred solution becomes entrenched. FEED should consequently document why an option was selected, what alternatives remain viable and which assumptions could require reconsideration. Validation and maturation serve different purposes: improving the definition of a selected solution does not prove that the solution is the best response to the underlying need.

Flyvbjerg [5] explains the outside view as a means of improving due diligence and countering biased forecasts. External comparison complements engineering estimates by testing whether the proposed cost, duration and benefit assumptions are consistent with comparable projects. The review does not reinterpret this work as a direct causal test of FEED maturity. Its contribution is an assurance method for challenging a technically detailed but optimistic investment case.

Combining validation and external benchmarking suggests two distinct gate questions. Has the team selected a defensible project concept? Has it developed that concept sufficiently to support the next commitment? Both require explicit evidence. A decision can fail either because its engineering basis is inadequate or because its objectives, demand assumptions and preferred alternative were never critically tested.

4.4 Site information and cross sector adaptation

Spyropoulos and Khan [6] examine differences between geotechnical campaigns at FEED and detailed design. Their case highlights the consequences of subsurface information and assumptions changing as design progresses. It provides a mechanism specific example rather than a general effect size. For infrastructure assessment, investigation adequacy should be linked to the decisions it must support, including alignment, foundations, construction methods and contingency.

Sector adaptation requires equivalence of decision function rather than identical document labels. Process flow diagrams may be relevant to treatment plants or industrial facilities; network models, route studies and demand assessments may be central to water, transport and telecommunications. A questionnaire that requires process industry deliverables for all sectors risks classifying inappropriate items as missing. The assessment must identify applicable elements, explain exclusions and retain a common core for comparison.

4.5 Sustainability and stakeholder value

Rahat et-al [7] connect Envision sustainability criteria with PDRI elements for infrastructure planning. This extends front end assessment beyond conventional scope definition and cost control. The mapping provides a way to examine compatibility between sustainability objectives and preparation activities; it should not be interpreted as independent validation of a Ugandan sustainability score.

Zerjav et-al [8] examine the multiplicity of value in the front end of London transport projects. Their work supports attention to how stakeholders define and negotiate project value. This matters because community access, affordability, environmental protection and service reliability may conflict with a sponsor's preferred engineering

or financial solution. Alignment should mean that priorities, disagreements and responsibilities are understood and documented, rather than that every stakeholder has agreed.

For Uganda, this review proposes that consultation be connected to design decisions through a traceable record of issues, responses and residual disputes. A consultation attendance list is insufficient evidence that land, access or service concerns have been incorporated. Public value should be examined through the distribution and durability of benefits as well as aggregate economic returns. These are analytical recommendations requiring contextual testing.

4.6 Recent attention to capital discipline

Greig et-al [9] discuss capital discipline in emerging net zero energy investments, warning that pressure to accelerate deployment can weaken investment rigor. Their relevance to this review is the tension between policy urgency and preparation quality, rather than a directly transferable estimate of FEED benefits. A strategic objective can justify prioritizing a project without establishing that it is technically or financially ready for execution.

A contemporary readiness approach should disclose the consequences of proceeding under unresolved uncertainty. It should identify which activities can safely advance, what capital becomes exposed and which decisions remain reversible. Digital engineering can support traceability and interface checks, but a model's visual detail does not establish the reliability of its assumptions. This review makes no quantified claim that adopting a particular digital technology improves FID quality.

V. CRITICAL SYNTHESIS AND IMPLICATIONS FOR UGANDA

The strongest direct evidence in this selected literature concerns FEED measurement and cost associations in large industrial projects. Complementary sources address infrastructure definition, validation, stakeholder value and investment discipline. Together they support treating front end preparation as a decision support process. They do not establish that FEED alone determines project outcomes, or that a particular score guarantees successful delivery.

Three limitations affect interpretation. First, observational comparisons are vulnerable to confounding: capable sponsors may prepare stronger FEED and execute more effectively. Second, retrospective assessment may be influenced by known outcomes, particularly when the same informants rate preparation and performance. Third, cost growth depends on the baseline selected. Comparing final cost with the original investment approval differs from comparing it with a later revised budget. These limitations require dated evidence, separate assessors and consistent outcome definitions.

Uganda already has institutional infrastructure for public investment information. The Ministry of Finance's Integrated Set of Projects is described as a central repository across the public investment lifecycle [10]. Ministry report also identifies the National Public Investment Management Policy as covering planning, appraisal, implementation and post evaluation [11]. FEED assurance should therefore be designed to complement existing processes rather than presume that project appraisal arrangements are absent.

The contextual problem is how engineering evidence is represented, challenged and retained when an investment commitment is made. This review proposes a link between project preparation records and approval conditions, followed by verification during procurement and execution. The analysis does not infer that every reported delay arose from inadequate FEED. Funding disruption, exchange rates, contractor performance, litigation and changes in policy can affect well prepared projects.

Public funding categories must also be distinguished. A ministry sponsored road, a state-owned utility investment and a privately financed project with public regulatory oversight differ in accountability and financing exposure. For future Ugandan research, inclusion criteria should state ownership, source of finance, delivery arrangement and the identified commitment milestone. Projects without a formal FEED stage can be included only where an equivalent definition package and approval boundary are observable.

The literature gap is thus bounded rather than absolute: the selected evidence provides limited direct validation of a project level FEED–FID–performance pathway across Ugandan public infrastructure sectors. A claim that no African research exists, or that the proposed study is the first, would require a more comprehensive bibliographic search than conducted here.

VI. PROPOSED INTEGRATED FRAME WORK FOR INVESTMENT READINESS

The proposed framework links four elements: technical definition, credibility of assurance, documented decision quality and subsequent public value [1–5, 8]. Institutional capacity, procurement arrangements and external uncertainty influence these relationships. Operations and post project evaluation provide feedback into future preparation. The framework is an author developed synthesis of the reviewed approaches; its dimensions and gate conditions are not a validated measurement instrument.

Technical definition establishes the selected scope, investigations, system boundaries and interfaces [2]. Assurance examines the provenance and verification of critical assumptions [3, 5]. FID effectiveness captures whether decision makers use this evidence to set a realistic baseline and document approval conditions. Execution outcomes include changes, cost and duration, while operational outcomes include service availability, maintainability and benefit realization. The distinction prevents construction completion from being treated as proof of public value [8].

At a readiness review, unresolved issues should be classified by their consequences for commitment [4, 5]. The proposed decision options are to approve subject to enforceable conditions, defer for further preparation or reject the investment case. Conditional approval must identify an accountable owner, evidence of closure, deadline and spending restriction. It should not disguise a fundamental uncertainty about technical feasibility, affordability or the lawful availability of the site.

A maturity index may be useful for diagnosing progress [1, 2], but approval should combine that index with mandatory conditions and an explicit residual risk assessment. Weights and cutoffs require sector calibration. An experimental study should compare assessment results with independent expert judgments and observed outcomes before any score is assigned [1, 3]. The suggested dimensions are summarized in Table 2; they are intended to guide verification, not to prescribe unsupported national thresholds.

For public investments, appraisal should distinguish financial affordability from economic desirability [12]. A water or transport project can generate public benefits without a positive financial return to its operator, while still requiring credible provision for operation and maintenance. FEED assumptions should be consistent with demand forecasts, capital expenditure, operating costs and implementation timing. Sensitivity tests should identify changes that would overturn the investment rationale [12].

VII. RESEARCH AGENDA AND PRACTICAL RECOMMENDATIONS

Future evaluation should use the project as the unit of analysis and freeze the evidence package at the defined investment milestone [1–3]. Independent assessors should rate maturity from engineering records and assurance from review documents. FID quality should be measured using approval minutes, appraisal records, documented dissent, funding commitments and conditions. Outcomes should come from audited costs, dated schedules, change registers and operating records rather than perception alone [13].

Cost growth can be defined as 100 × (final comparable cost − approved comparable cost) / approved comparable cost. Schedule growth can be defined similarly using actual and approved durations. Currency, price basis, scope boundaries and approved changes must be recorded [1, 5]. Unfinished projects require separate treatment because their final outcomes are cut. Deferred and rejected investments should also be studied: a readiness process can create value by avoiding an unsuitable commitment [4, 5].

Multiple informants improve measurement coverage but do not increase the number of independent projects [14]. A portfolio of approximately 30 projects, as proposed in the source document, would remain a small project level sample even with several respondents per project. Complex mediation and multiple moderation models could be unstable [15]. Initial analysis should emphasize descriptive comparisons, parsimonious models, uncertainty intervals and qualitative process tracing. Larger coordinated portfolios would be needed for more demanding model tests.

The proposed questionnaire should separate agreement with general FEED benefits from evidence about a particular project. Endorsing the statement that strong FEED reduces overruns is not a test that a relationship exists in observed project outcomes [13]. Likewise, a binomial agreement test cannot establish mediation or causation. The source proposal's inconsistent five and seven category scale references should be resolved before piloting. Sector specific item applicability, documentary checks and interrater agreement should be established before aggregation [16].

Four propositions follow from the synthesis. Greater technical definition is expected to be associated with fewer post approval changes originating in unresolved scope [1, 2]. Stronger independent assurance is expected to improve the credibility of investment baselines beyond completeness alone [3, 5]. Documented decision quality may mediate part of the relationship between preparation and performance, although temporal evidence is needed to test this mechanism [17]. Governance arrangements may influence whether identified deficiencies are corrected before capital commitment. These are testable propositions, not findings from Ugandan fieldwork.

Implementing agencies should budget for investigations and definition activities according to the uncertainties that materially affect their decisions [2, 6]. Review teams should include engineering, finance, procurement, safeguards and future operations functions [2, 12]. Approval records should state baseline assumptions, unresolved interfaces and the authority accepting residual risk [4, 5]. Changes after approval should be coded by origin so that preparation failures can be distinguished from external disruptions and legitimate scope adjustments.

At portfolio level, the practical priority is a traceable engineering assurance record connected to existing public investment information systems [10, 11]. Standardization should establish a common readiness core while

preserving sector annexes. Independent reviews should concentrate on critical uncertainties rather than document volume [3, 5]. Periodic evaluation should examine whether these reviews change decisions and improve public outcomes, including their cost and preparation time.

VIII. LIMITATIONS

This review relies on selected sources and the supplied proposal, with varying access to full articles. It cannot establish exhaustive coverage, exclude publication bias or estimate pooled effects. Industrial evidence is more developed in the selected corpus than public infrastructure evidence, and potentially overlapping samples restrict independent corroboration. No Ugandan project dataset was analyzed. The proposed framework therefore requires stakeholder review, measurement validation and longitudinal testing before it is used as a binding investment gate.

IX. CONCLUSIONS

The reviewed evidence supports FEED as a structured means of improving the information available before capital commitment, while showing that maturity, completeness, quality and accuracy represent different aspects of readiness. Industrial studies demonstrate associations with cost performance, but do not justify universal effect sizes or automatic transfer of thresholds to Uganda. Investment decision quality depends on whether engineering evidence is independently challenged, connected to affordability and public value, and translated into documented conditions. The proposed framework combines sector appropriate definition, assurance and approval discipline within Uganda's existing public investment setting. Its principal research requirement is a longitudinal project record that separates preparation quality, decision behavior and external execution influences. Such evidence would permit calibration of readiness assessments and a more defensible evaluation of their contribution to public infrastructure performance.

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Tables

Table 1 Evidence and transfer limitations

Source	Contribution	Evidence boundary
[1] Yussef et al 2019	FEED maturity assessment and industrial cost association	33 industrial projects observational comparison
[2] CII 2011	Infrastructure scope definition and repeated PDRI review	Historical threshold requires local calibration
[3] Gibson et al 2024	Confidence in FEED maturity and organizational environment	Potential sample overlap with [1]
[4] Grau et al 2021	Validation of alternatives before authorization	Complementary conceptual phase practice
[5] Flyvbjerg 2013	External benchmarking to challenge biased assumptions	Not a direct FEED maturity effect estimate
[6] Spyropoulos and Khan 2020	Geotechnical information across design stages	Case specific mechanism
[7] Rahat et al 2023	Sustainability and PDRI mapping	Framework mapping requires contextual testing
[8] Zerjav et al 2021	Multiple stakeholder definitions of value	London transport context
[9] Greig et al 2025	Investment rigor under policy pressure	Emerging energy investment context

Table 2 Proposed readiness dimensions for Uganda

Dimension	Evidence to examine	Decision question
Technical definition	Design basis investigations interfaces sector deliverables	Is scope defined for the commitment?
Assurance credibility	Independent reviews assumption provenance closure records	Can critical information be trusted?
Cost and schedule	Estimate basis risk ranges critical path funding timing	Are baselines realistic and consistent?
Safeguards and stakeholders	Approval status land access issues and responses	Are unresolved issues acceptable?
Commercial readiness	Contract strategy market evidence risk allocation	Can the package be procured responsibly?
Affordability and public value	Economic appraisal operating budgets demand scenarios	Are benefits credible and costs supportable?
Decision governance	Approval authority dissent conditions accountable owners	Is commitment traceable and conditional where needed?
Learning and outcomes	Change origins audited performance service indicators	What should improve in future preparation?

Tables are author developed syntheses. Table 2 describes proposed verification dimensions rather than validated weights or approval thresholds.