The Invisible Hands Phenomenon: Epistemic Injustice and Gendered Credibility in Engineering Commissioning.

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ABSTRACT

Commissioning engineering is a critical yet under-examined phase in which complex systems transition from construction to operation under conditions of high uncertainty, time pressure, distributed authority, and elevated safety risk. Despite extensive scholarship on gender inequality in engineering, commissioning remains almost absent from this discourse, even though its defining characteristics are precisely those under which credibility, authority, and recognition are most contested. Drawing on epistemic injustice theory, this paper introduces the *Invisible Hands Phenomenon*: a conceptual framework describing how preventative, anticipatory, and integrative technical work becomes organisationally invisible through credibility deflation, visibility asymmetries, and attribution gaps. Three analytically derived manifestations are theorised—task allocation through credibility circuits, safety voice and strategic invisibility, and cumulative credibility-deficit cascades—illustrating how epistemic injustice may become embedded in everyday commissioning practice. Positioning commissioning as a critical case, the framework clarifies mechanisms through which technical authority and recognition are unevenly distributed, with implications for safety performance, career progression, and organisational learning. The paper provides a foundation for future empirical research examining gendered dynamics in commissioning environments and contributes to broader debates on equity, knowledge, and authority in engineering work.

KEYWORDS: Commissioning engineering; Epistemic injustice; Gender in engineering; Technical authority; Safety voice; Task allocation; Credibility dynamics

1. INTRODUCTION

Commissioning plays a decisive role in verifying and integrating complex engineered systems, yet it remains one of the least examined phases of the project lifecycle. Commissioning involves the verification, integration, and performance validation of complex systems before operational handover and is characterised by high technical uncertainty, time-compressed problem-solving, and elevated safety risk (Whyte et al., 2016). Despite its importance for project performance, existing work indicates that commissioning receives far less scholarly attention than design, construction, or steady-state operations (Singh and Anumba, 2024). This omission is notable given that commissioning environments often involve irregular rosters, live troubleshooting, and cross-disciplinary coordination—conditions under which team dynamics, authority, and perceptions of competence become acutely visible (Locatelli et al., 2014).

In parallel, a substantial body of research documents persistent gender inequalities in engineering. Systematic reviews and longitudinal analyses show that women continue to face structural barriers related to workplace culture, implicit bias, stereotyping, task allocation, and unequal recognition of technical expertise (Cech, 2013; Faulkner, 2009; Seron et al., 2016). Studies also show that women's career persistence is shaped by gender identity, role congruity, legitimacy challenges, and differential access to high-value learning opportunities (Cech and Blair-Loy, 2019; Powell et al., 2009). Contemporary analyses further highlight how masculine norms in engineering—such as expectations of constant availability, crisis response, and field-based presence—shape professional experiences and opportunities for advancement (Kelan, 2017; Riley et al., 2014).

Yet, despite this extensive scholarship, research remains heavily concentrated on recruitment, education, early-career transitions, and retention (Ewim and Dosunmu, 2025; Washizaki, 2022). Very little work examines how gendered experiences vary across specific engineering subdomains or project phases (Powell et al., 2009). Commissioning, arguably one of the most demanding and consequential phases of engineering work, is almost absent from this discourse. Commissioning represents a critical case because its defining conditions—uncertainty, time pressure, and ambiguous authority—intensify the organisational processes through which gendered credibility dynamics operate.

This omission is theoretically significant. Commissioning environments amplify the conditions under which gendered organisational processes intensify: uncertainty, high risk, time pressure, and ambiguous authority structures. Theories of gendered organisations (Ely and Meyerson, 2000) and role congruity (Heilman, 2012) suggest that in male-typed, high-stakes technical settings, women may experience greater barriers to legitimacy, reduced access to hands-on tasks, lower recognition for technical contributions, and heightened scrutiny during failure events. Emerging research in adjacent high-risk sectors indicates that gender influences safety voice,

risk communication, and perceived authority (Morrison, 2011; O'Connor et al., 2008), suggesting similar dynamics may be present—but currently undocumented—within commissioning teams.

The implications extend beyond commissioning practice itself. Commissioning experience is widely recognised as a gateway to senior technical and operational roles, providing engineers with system-level understanding, leadership experience, and credibility in risk-critical environments (Bosch-Rekveldt et al., 2011; Whyte et al., 2016) If women face exclusion from commissioning opportunities, or if their contributions are undervalued within commissioning teams, this may directly shape gender disparities in senior engineering leadership pipelines. Given global efforts to strengthen gender equity in engineering and evidence that diverse engineering teams outperform on innovation, safety, and organisational performance (Clarke, 2013), understanding gendered dynamics within commissioning environments is both academically and industry relevant.

This paper asks: How are credibility, authority, and recognition gendered during the commissioning phase of engineering projects, and how can epistemic injustice theory illuminate these dynamics?

2. METHODS

As this is a conceptual analysis, the search strategy aimed to map the theoretical landscape rather than exhaustively catalogue all technical commissioning literature. As the purpose of this study is conceptual development and gap identification rather than empirical analysis, the scope is appropriately limited to synthesising existing literature across adjacent domains.

2.1 Literature Search Strategy

Structured database searches were conducted in Scopus to confirm the absence of scholarship at the intersection of commissioning engineering and gender, rather than to produce an exhaustive systematic review. Scopus was selected for its comprehensive coverage of peer-reviewed engineering, construction, and interdisciplinary social science literature (Baas et al., 2020). For gap identification in a niche intersection, a single high-quality database with precise Boolean functionality is methodologically sufficient (Gusenbauer and Haddaway, 2020).

An initial broad search combining "engineering AND commissioning" returned 4,664 documents, yet "engineering AND commissioning AND gender" returned three results. However, a full-text review revealed that none of the three results examined gendered experiences within commissioning work (Cinelli, 2022; Haider and Groemer, 2010; Hargreaves, 2009).

A structured Boolean search was then conducted to capture the intersection of three concept domains systematically:

- **Commissioning activities**: (commissioning OR startup OR start up OR pre operational OR systems integration OR project delivery)
- **Engineering contexts**: (engineering OR construction OR infrastructure OR technical workforce)
- **Gender/equity dimensions**: (gender OR women OR diversity OR equity OR inclusion OR "organisational culture" OR authority OR "task allocation")

This search strategy returned:

- Commissioning activities alone: 482 results
- Combined with engineering contexts: 12 results
- Combined with gender/equity terms: **0 results**

Of the 12 papers identified in the Boolean search, five were in the medical field and were discounted, leaving the remaining seven for further analysis.

One paper discusses recruitment and talent development in the New York City Department of Environmental Protection (Edwards et al., 2016). Still, none of the documents addressed workforce dynamics, organisational culture, and gendered experiences. The purpose of this search strategy was to identify gaps and to identify positioning concepts consistent with the scoping approaches used in emergent research areas. As a conceptual analysis, the aim is not empirical generalisation but theoretical clarification; the framework developed here is intended to guide and structure future empirical inquiry.

2.2 Literature Review Approach

Given the absence of research at the commissioning-gender intersection, the literature review synthesises insights from three distinct bodies of scholarship: (1) gender in engineering workplace research, (2) commissioning technical literature, and (3) related organisational phenomena, including safety voice, gendered task allocation, and field-based work dynamics. Sources were identified through targeted searches, citation chaining from recent reviews, and examination of key journals in each domain (e.g., *Engineering Studies*, *Gender Work & Organisation*, *Safety Science*, *Construction Management and Economics*).

This approach enables conceptual synthesis across adjacent literatures to establish theoretical foundations for examining an empirically unexplored intersection, consistent with scoping review methodology for emergent research areas (Arksey and O'Malley, 2005).

2.3 Theoretical Development Approach

This paper develops theoretical predictions in advance of empirical testing. The conceptual framework presented here—including the Invisible Hands Phenomenon and its three manifestations—represents theorized mechanisms derived from systematic synthesis of gender studies, commissioning practice literature, and epistemic injustice theory. These constructs establish testable predictions for subsequent empirical examination.

This theory-first approach is methodologically appropriate when: (1) empirical research is demonstrably absent, as confirmed through systematic searching (Section 2.1); (2) adjacent literatures provide robust conceptual foundations for inference; and (3) clear, falsifiable predictions can be articulated for future validation. Developing theoretical frameworks before empirical testing protects against post-hoc rationalization of observed patterns and enables hypothesis-driven research design.

The framework developed here provides a foundation for empirical studies currently in progress, including observational research, interview studies, and survey-based investigations of gendered dynamics in commissioning environments. Claims presented in Sections 4-5 should be understood as theoretical predictions grounded in established literatures rather than empirically documented observations.

3. CONCEPTUAL FOUNDATIONS AND GAP MAPPING

3.1 An Unexplored Intersection

Systematic searching confirmed that zero peer-reviewed studies examine gender within commissioning engineering contexts. This finding held across multiple search strategies and confirmed that commissioning represents an empirically neglected phase within engineering gender scholarship.

Research on commissioning exists and is substantial (4,664 results for "engineering AND commissioning"), indicating it is a recognised engineering domain. However, this literature remains predominantly technical. The seven papers identified as addressing both commissioning and engineering contexts (Al-Mhdawi et al., 2023; Athaide et al., 2025; Edwards et al., 2016; Ibrahim et al., 2020; Kalyanam, 2019; Lavelle, 2007; March et al., 2003). None examines workforce composition, task allocation, authority structures, or gendered experiences.

This constitutes a significant empirical gap. Commissioning’s documented characteristics—technical uncertainty, time pressure, high operational visibility, cross-functional coordination, and safety criticality—align closely with conditions under which gender scholarship predicts differential experiences. Yet these dynamics remain unexamined.

3.2 Conceptual Foundations from Adjacent Literatures

3.2.1 Women in engineering: persistent inequalities

Research consistently demonstrates that women remain under-represented and unevenly distributed across engineering disciplines, career stages, and organisational hierarchies. Inequality is reproduced through everyday organisational processes rather than individual deficits, highlighting the structural character of gendered disadvantage (Faulkner, 2009).

Contemporary scholarship extends beyond numerical representation to examine belonging, occupational identity, and perceived fit. Studies show that women engineers navigate gendered organisational norms that shape legitimacy, identity, and access to technical authority (Cech, 2013). Senior women often face cumulative barriers, including marginalisation from influential networks and constrained access to high-value technical work (Williams et al., 2014).

Work–family scholarship provides essential insights into attrition patterns. Women engineers experience heightened work–family conflict, reduced organisational support, and greater career penalties post-parenthood relative to men (Cech and Blair-Loy, 2019). Longitudinal analyses reveal that family formation often leads to downgraded roles or exit from technical tracks, with long-term implications for representation at senior levels (Glass et al., 2013). Intersectional studies further highlight how cultural norms, socio-political conditions, and institutional constraints shape women's experiences in diverse engineering contexts (Riley et al., 2014).

Despite the breadth of research, the existing literature treats engineering work as homogeneous. It seldom disaggregates women's experiences by project phase—such as design, construction, commissioning, or operations. As a result, little is known about how specific engineering contexts shape gendered experiences.

3.2.2 Commissioning in engineering projects

Commissioning is widely recognised as a critical phase in which engineered systems are verified, integrated, and prepared for operation. Research in construction and project management characterises commissioning as a structured process linking installation, functional testing, and performance validation. Commissioning has been shown to influence overall project quality, system performance, and operational readiness, yet recent reviews emphasise a lack of consistent documentation practices and methodological standardisation (Singh and Anumba, 2024).

Recent work has examined commissioning within broader shifts toward digital transformation, including the emergence of continuous commissioning and data-driven optimisation (Katipamula and Brambley, 2005). Research on systems integration and late-phase project delivery further suggests that commissioning in large infrastructure

projects demands advanced interdisciplinary competencies and decision-making under uncertainty (Whyte et al., 2016).

3.2.3 Gendered organisations and role congruity

Theories of gendered organisations and role congruity provide strong conceptual foundations for anticipating gendered patterns in commissioning environments. Acker's theory of gendered organisations argues that organisational processes, structures, and interactions are implicitly gendered, disadvantaging women through seemingly neutral practices such as evaluation, task allocation, and expectations of availability (Acker, 1990). Subsequent work extends this perspective, demonstrating how organisational cultures and logics reproduce gendered patterns of recognition, authority, and legitimacy (Britton, 2000; Williams, 2013).

Within engineering, women often experience organisational cultures that position them as exceptions, shaping role expectations and access to high-value technical work (Cech, 2013; Williams et al., 2014). Role congruity theory holds that prejudice arises when a mismatch is perceived between gender stereotypes and role demands, leading to stricter competence evaluations for women in technical roles (Heilman, 2012).

Experimental studies further show that women are disproportionately selected into precarious or high-blame roles and are evaluated more harshly in ambiguous performance conditions. Taken together, these frameworks suggest that in male-typed, high-visibility technical settings, women may encounter constrained access to hands-on work, increased scrutiny of competence, and difficulties in establishing technical legitimacy. Commissioning, which demands rapid technical judgment and carries high operational visibility, represents a plausible site for such dynamics, yet it has not been studied empirically (Eagly and Karau, 2002).

3.2.4 Safety, risk, and voice in high-risk work

Commissioning occurs when systems are not yet stable, and errors may have significant safety consequences. Research from high-risk fields shows that women exhibit different patterns of safety-voice intention than men, particularly in contexts involving uncertainty (Tucker et al., 2014). Although these studies do not examine commissioning, they indicate that gender is relevant to safety voice, hazard perception, and authority in high-risk technical settings. Given commissioning's time pressure, interdisciplinary coordination, and ambiguous authority lines, similar dynamics may arise, yet the commissioning literature has not investigated safety or risk through a gendered lens.

3.2.5 Work–life relations, mobility, and commissioning-type roles

Work–life research shows that women are more likely to experience work–family conflict in occupations with long hours, travel demands, or rigid scheduling. Extended working hours and expectations of constant availability contribute to attrition (Cech & Blair-Loy, 2019), while family formation reduces participation in technical or project-based roles. Research on women in construction and site-based engineering shows that mobility requirements, irregular hours, and project-based deployment create retention challenges, particularly where gender norms and limited institutional support intensify work–family tensions.

Commissioning roles are typically characterised by extended or irregular shifts, on-site presence, travel to remote locations, and periods of concentrated workload around start-up milestones. Although project management research acknowledges these features, evidence is limited on how women experience them and on how commissioning-specific working conditions influence career decisions. Taken together, these literatures suggest that commissioning is a theoretically rich but empirically unexamined site for understanding gendered dynamics in engineering practice.

3.3 Research Gap and Study Objectives

Three key insights emerge from this review. First, gender inequalities in engineering remain well documented, and recent work highlights the organisational processes through which they are reproduced. Second, commissioning has been established as a critical phase within project delivery, yet the research remains predominantly technical and does not examine the commissioning workforce (Singh & Anumba, 2023). Third, theories and empirical studies from gendered organisations, role congruity, safety-voice research, and work–life scholarship strongly suggest that gender is likely to shape experiences within commissioning environments.

Despite this, empirical studies examining gender, diversity, or equity within commissioning engineering roles are virtually absent, and current evidence indicates that research does not consider how women experience commissioning work—including task allocation, technical authority, and career progression. This omission defines a clear and significant gap in the literature that the present study addresses.

The literature also points to recurring patterns in task allocation, safety voice, and recognition during commissioning work. To interpret these patterns, the following section draws on epistemic-injustice theory to explain how credibility, authority, and visibility shape technical decision-making in commissioning environments (Ridgeway, 2001).

Given these intersecting gaps, conceptual development is both timely and necessary. Commissioning represents a theoretically rich but empirically unexamined environment in which gendered organisational processes are likely to manifest in distinctive ways.

Before empirical studies can be meaningfully designed, the field requires a coherent conceptual framework that articulates the mechanisms through which credibility, authority, and recognition operate in commissioning contexts. This paper provides that foundation.

3.4 Why Gender Matters Specifically in Commissioning Contexts

While credibility dynamics in commissioning intersect with seniority, disciplinary background, and organisational tenure, gender remains a structurally salient axis through which epistemic disadvantage is produced and sustained. Commissioning work intensifies reliance on traits culturally coded as masculine—decisiveness under uncertainty, visible technical confidence, physical presence during extended site-based work, and tolerance for risk exposure. Extensive gender scholarship demonstrates that when technical authority is evaluated under conditions of ambiguity and time pressure, women are more likely to experience credibility deflation, heightened scrutiny, and constrained access to high-visibility tasks, even when formal qualifications are equivalent. In commissioning environments, where authority is negotiated in real time rather than secured through documentation or hierarchy, these gendered credibility assessments are particularly consequential. As a result, women engineers are systematically more exposed to attribution gaps, the invisibility of preventive work, and cumulative credibility loss, making gender not incidental but constitutive of how epistemic injustice manifests during commissioning.

While this analysis focuses primarily on gender, it is essential to acknowledge that commissioning environments are shaped by intersecting axes of inequality, including race, age, nationality, organisational status, and disciplinary background. Intersectional scholarship demonstrates that credibility and authority are not distributed evenly among women, and that women who occupy multiple marginalised identities may experience compounded forms of epistemic disadvantage. Although the present framework does not empirically examine these intersections, it provides a foundation for future research to explore how gender interacts with other social categories to shape credibility, visibility, and authority in commissioning teams.

While other engineering contexts also involve high pressure or risk, commissioning is distinct in its temporary authority structures, attribution lag, and transitional status between delivery and operation. Unlike operations, where authority stabilises over time, or construction, where contractual hierarchies are clearer, commissioning concentrates uncertainty, responsibility, and retrospective accountability within a compressed temporal window. These features make commissioning a critical case in which credibility dynamics are particularly consequential.

4. INTERPRETING THE LITERATURE: EPISTEMIC INJUSTICE IN COMMISSIONING

Gender is analytically central in this framework, not because it is the only axis of epistemic disadvantage, but because it represents a structurally persistent, socially codified credibility marker within engineering cultures, shaping authority assessments across career stages.

4.1 Epistemic Injustice in Technical Work

Epistemic injustice refers to structural and interactional processes through which individuals are unfairly disadvantaged in their capacity as knowers. In commissioning environments, it shapes whose technical judgments are trusted, whose interpretations are acted upon, and whose contributions become visible within organisational narratives.

The dynamics of credibility and recognition in commissioning practice can be productively analysed through this lens. Epistemic injustice captures forms of unfairness that arise when individuals are disadvantaged specifically in their capacity as knowers (Fricker, 2007). Rather than operating through explicit exclusion, it is typically embedded in everyday judgments about credibility, authority, and whose interpretations are taken seriously. In high-stakes technical work, these judgments can have material consequences for both individual careers and collective performance.

Two forms of epistemic injustice are particularly salient for understanding commissioning dynamics: testimonial injustice and hermeneutical injustice. Testimonial injustice occurs when a speaker's credibility is systematically deflated due to identity-linked assumptions rather than the substance of their contribution (Fricker, 2007). In commissioning contexts, this manifests when technical warnings, interpretations, or recommendations are questioned, minimised, or overridden based on who delivers them, even when comparable contributions from others are readily accepted. These credibility assessments are rarely explicitly framed as bias; instead, they emerge from routine interactions shaped by familiarity, perceived authority, and time pressure.

Hermeneutical injustice arises when there is a lack of shared interpretive resources to make sense of specific experiences (Fricker, 2007). In commissioning work, this becomes evident in the difficulty of articulating forms of technical judgment that involve anticipation, unease, or preventative intervention. When organisational language privileges visible failures, formal test outcomes, or decisive interventions, quieter forms of sensemaking and risk avoidance may lack recognised status. As a result, some technical contributions become difficult to name, document, or defend retrospectively.

These forms of epistemic injustice are likely to be amplified in commissioning environments. Commissioning decisions are made when systems are incomplete, behaviours are unstable, and formal documentation often lags real-time conditions. Under such circumstances, technical judgment and experiential knowledge carry heightened importance. At the same time, commissioning is highly visible: delays are costly, failures are public, and accountability is often assigned after the fact. In this context, credibility functions as a key organising mechanism, shaping who is trusted, whose judgments are acted upon, and whose contributions are remembered.

4.2 Commissioning as an Epistemically Vulnerable Environment

Commissioning environments exhibit a constellation of structural conditions that render them particularly vulnerable to epistemic injustice. These conditions do not operate independently; instead, they interact to intensify the consequences of credibility assessments and interpretive gaps in technical decision-making.

First, commissioning is characterised by high technical uncertainty. Systems are newly integrated, operating parameters are still being established, and unexpected interactions may occur daily. Decisions must often be made with incomplete information, requiring engineers to rely on judgment rather than procedural certainty.

Second, commissioning unfolds under acute time pressure. Start-up schedules, contractual milestones, and operational constraints compress decision windows and limit opportunities for extended deliberation. Under these conditions, rapid consensus is often prioritised, and dissenting or cautious interpretations may be reframed as obstructive or commercially naïve.

Third, commissioning involves distributed and ambiguous authority. Responsibility is shared across designers, contractors, vendors, operators, and commissioning engineers. Formal hierarchies do not always align with situational expertise, particularly when troubleshooting novel or emergent problems.

Fourth, commissioning work exhibits pronounced visibility asymmetries. Certain activities—such as leading live tests, making decisions in control rooms, or interfacing with senior stakeholders—are obvious and readily attributed to individuals. Other forms of work, including preparatory checks, incremental adjustments, and preventative interventions, remain largely unseen.

Together, these conditions create an epistemically vulnerable environment in which credibility judgments carry disproportionate weight. This structural vulnerability provides fertile ground for epistemic injustice to emerge, particularly affecting engineers whose authority is already socially contested due to gender, race, age, organisational outsider status, or disciplinary background (Whyte et al., 2016; Bosch-Rekveldt et al., 2018; Larsen et al., 2018). The following section introduces the

Invisible Hands Phenomenon as a specific manifestation of how epistemic injustice operates within these commissioning conditions.

From a gender studies perspective, these epistemic vulnerabilities matter because credibility assessments are not socially neutral; they systematically privilege forms of authority and visibilitalignedgn with masculine norms of technical competence, increasing the likelihood that women's commissioned knowledge is discounted or rendered invisible.

4.3 The Invisible Hands Phenomenon

The Invisible Hands Phenomenon theorises a pattern in which preventative, anticipatory, or integrative technical work becomes organisationally invisible due to credibility dynamics, attribution gaps, and the absence of recognised interpretive resources. It predicts that essential commissioning contributions—particularly those that avert failures or stabilise systems—will be systematically under-recognised, weakly attributed, or retrospectively erased.

Three mechanisms are theorised to underpin the Invisible Hands Phenomenon: (1) Credibility deflation, in which preventative judgments are discounted or questioned. (2) Visibility asymmetry, whereby high-value anticipatory work leaves no observable trace. (3) Attribution gaps, where successful outcomes are decoupled from the individuals whose interventions enabled them. Together, these mechanisms are predicted to produce cumulative credibility deficits that shape authority, safety voice, and career progression.

To account for the epistemic dynamics identified above, this study introduces the Invisible Hands Phenomenon as an analytically grounded construct. It captures a pattern in which technical contributions essential to system performance remain organisationally invisible, weakly credited, or retrospectively erased.

In commissioning contexts, certain forms of technical work involve anticipation, coordination, and preventative judgment. These include identifying subtle inconsistencies before they escalate, adjusting parameters to avert failures, coordinating across disciplines to prevent conflicts, and maintaining safety margins under uncertain conditions. Although such actions are expected to shape commissioning outcomes materially, they are likely to leave no visible trace. When success is defined as the absence of failure, it becomes structurally complex to attribute positive outcomes to specific acts of judgment or intervention.

The Invisible Hands Phenomenon is closely linked to testimonial injustice. When technical contributions occur outside visible decision-making arenas—in preparatory checks, incremental adjustments, or quiet problem prevention—the engineers responsible may not be recognised as authoritative, even when their work proves

consequential. Over time, this is theorised to produce credibility gaps in which specific individuals are repeatedly absent from organisational narratives of technical success.

The phenomenon also reflects hermeneutical injustice. Organisational accounts of commissioning typically privilege dramatic breakdowns, decisive interventions, or formally documented achievements. There is often no shared language for recognising avoided risks, stabilised systems, or incremental improvements achieved through anticipatory work. As a result, engineers engaged in such work face systematic difficulty articulating their contributions in ways that align with prevailing evaluative frameworks.

Critically, theory predicts that invisibility is not evenly distributed. Engineers already positioned at the margins of credibility hierarchies—whether due to gender, seniority, disciplinary background, or organisational outsider status—are predicted to be more vulnerable to having their work rendered invisible. Conversely, those with established authority benefit from retrospective attribution even when their direct involvement was limited. The Invisible Hands Phenomenon thus operates as a mechanism through which epistemic injustice becomes embedded in everyday commissioning practice, systematically disadvantaging those whose credibility is already contested.

Figure 1 presents a conceptual model of the epistemic ecology of commissioning. It illustrates how structural conditions create epistemic vulnerabilities that enable the Invisible Hands Phenomenon, and how these dynamics produce organisational consequences related to authority, safety voice, and career progression. The model synthesises the mechanisms identified in this section and provides a framework for future empirical investigation.

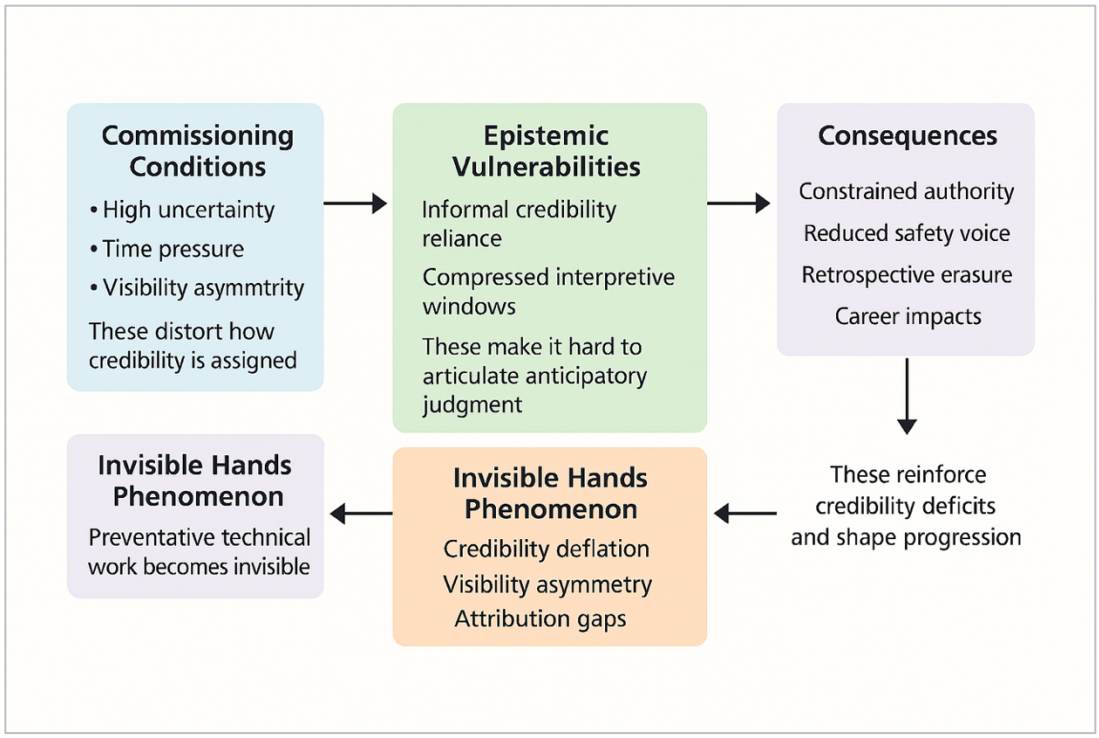

Figure 1. Epistemic ecology of commissioning work.

This conceptual model illustrates how commissioning conditions (high uncertainty, time pressure, distributed authority, visibility asymmetries) generate epistemic vulnerabilities that enable the Invisible Hands Phenomenon. The phenomenon is driven by credibility deflation, visibility asymmetry, and attribution gaps, resulting in constrained authority, reduced safety voice, retrospective erasure, and career impacts.

The model does not implthe y universality or inevitability of these dynamics; rather, it identifies mechanisms expected to intensify under particular organisational and temporal conditions characteristic of commissioning work.

5. MANIFESTATIONS OF EPISTEMIC INJUSTICE IN COMMISSIONING PRACTICE

The mechanisms described in this section are theoretically derived and analytically generative rather than empirically universal, articulating plausible patterned dynamics that warrant empirical investigation rather than claiming descriptive completeness across all commissioning contexts.

This section examines three interrelated manifestations of epistemic injustice in commissioning practice: task allocation through credibility circuits, safety voice and strategic invisibility, and cumulative credibility deficits over time. Although these credibility deficit cascades can affect any engineer at the margins of authority, gendered stereotypes about technical legitimacy, risk tolerance, and leadership make them more persistent and less reversible for women in commissioning-intensive roles.

5.1 Task Allocation and Credibility Circuits

Because credibility assessments are socially patterned, these circuits may disproportionately disadvantage engineers whose authority is already contested, including women in male-typed commissioning environments. Task allocation during commissioning is shaped not only by formal role definitions but by informal assessments of credibility and trust. As a result, high-visibility, system-critical tasks often concentrate among a subset of engineers, while others are assigned preparatory, coordinating, or support-oriented work. These patterns are rarely framed as gendered or hierarchical, yet they produce uneven access to commissioning experience and recognition (Cech, 2013; Williams et al., 2014).

High-stakes tasks—such as leading live testing, diagnosing system instability, or interfacing with senior stakeholders—function as markers of technical authority. Engineers assigned to these roles accumulate visibility and reputational capital, reinforcing organisational perceptions of competence. In contrast, lower-visibility tasks, despite being technically essential, are often positioned as supportive or ancillary. This

distinction shapes how contributions are valued retrospectively and how they are remembered organisationally.

Over time, these dynamics are theorised to form credibility circuits: feedback loops in which prior visibility influences future task allocation. Engineers perceived as credible are more likely to be entrusted with complex or risky work, further reinforcing their authority. Conversely, engineers whose contributions remain less visible encounter systematic constraints on future opportunities, even when their technical competence is comparable.

Epistemic injustice is predicted to operate within these circuits through two mechanisms. Testimonial injustice is expected to arise when engineers' knowledge claims or expressions of capability are discounted in task-allocation decisions (Fricker, 2007). Hermeneutical injustice compounds this effect by obscuring the technical significance of less visible contributions—preparatory work, risk mitigation, system stabilisation—making them difficult to name or defend as evidence of expertise. Together, these dynamics are theorised to shape the uneven accumulation of commissioning knowledge and authority.

Crucially, successful commissioning outcomes tend to be retrospectively attributed to visible interventions, while preparatory or preventative work fades from organisational memory. Such attribution patterns reinforce existing credibility hierarchies and influence subsequent role assignments across future commissioning cycles.

These dynamics suggest that task allocation is not merely an operational concern but a mechanism through which epistemic injustice is reproduced in commissioning practice. By shaping differential access to experience, visibility, and recognition, credibility circuits influence both immediate technical authority and longer-term career trajectories within commissioning-intensive roles.

5.2 Safety Voice and Strategic Invisibility

Theory predicts that safety voice during commissioning is shaped by credibility dynamics that determine whose concerns are heard, engaged with, and acted upon. In high-pressure commissioning environments, expressions of caution or identification of emerging risks do not automatically translate into technical engagement with the substance of the concern. Instead, safety-related input may be reinterpreted through personal or dispositional lenses, fundamentally altering the calculus of whether to speak up (Edmondson, 1999). Gender scholarship demonstrates that expressions of caution, uncertainty, or anticipatory concern are more readily interpreted as a lack of confidence or excessive risk aversion when voiced by women in male-typed technical environments, shaping whose safety concerns are taken seriously during high-pressure commissioning work.

Under acute time pressure, expressions of caution are predicted to risk being interpreted as risk aversion, lack of confidence, or insufficient commercial awareness. This reframing shifts attention away from the technical merit of the concern and toward perceived characteristics of the speaker. For engineers whose credibility is already contested, this creates a disincentive to raise safety issues, as doing so may reinforce rather than challenge existing credibility deficits (Detert and Burris, 2007). This dynamic aligns with broader findings in safety-critical work showing that risk communication is shaped as much by social credibility as by technical content (Tucker et al., 2014).

This dynamic is theorised to create a double bind. Speaking up carries the risk of dismissal or reputational marginalisation, while remaining silent increases the likelihood that technical judgment will remain invisible and unrecognised. Either choice involves epistemic cost. The decision to limit visible safety interventions, therefore, reflects strategic adaptation to credibility constraints rather than technical disengagement or lack of safety commitment.

Hermeneutical injustice is expected to shape this process further. Avoided incidents or concerns that were never raised leave no formal record, making it structurally difficult to demonstrate the value of precautionary judgment. When failures do not occur, prior silence may be retrospectively interpreted as confirmation that the concerns were unnecessary, rather than as evidence that preventive action succeeded. This creates an attribution asymmetry in which visible interventions during crises gain recognition while successful risk avoidance remains invisible.

The theorised practice of strategic invisibility in safety voice is predicted to have collective consequences for commissioning teams. When credibility constraints systematically mute certain forms of technical judgment, the team's epistemic capacity is reduced. Hazards may be identified later than optimally, learning opportunities may be missed, and responsibility for safety outcomes may become unevenly distributed across team members.

Safety voice in commissioning thus emerges as both a technical and an epistemic practice. Credibility dynamics determine not only who feels able to speak but whose safety knowledge is incorporated into collective decision-making. This has implications for both individual career trajectories and organisational safety performance in commissioning contexts.

5.3 The Credibility Deficit Cascade

The epistemic dynamics identified in task allocation and safety voice have cumulative implications that extend beyond individual commissioning episodes. This section introduces the credibility deficit cascade: a theoretical mechanism through which early

experiences of epistemic disadvantage during commissioning compound over time, reshaping access to learning, authority, and career progression.

The cascade is theorised to operate through sequential reinforcement of credibility gaps. When epistemic injustice reduces the visibility of certain engineers' contributions during commissioning, theory predicts that those individuals become less likely to be associated with successful outcomes in organisational memory. This invisibility constrains access to informal recognition and mentorship—forms of validation that are central to developing commissioning expertise and technical authority.

Reduced visibility then constrains knowledge-transfer opportunities. Engineers who are systematically excluded from high-visibility troubleshooting, system-level decision-making, or critical incident response accumulate less complex commissioning experience. Over time, this limited exposure may be retrospectively interpreted as a sign of limited capability, reinforcing initial credibility deficits rather than being recognised as a consequence of unequal task allocation.

As the cascade progresses, engineers facing persistent credibility gaps are excluded from high-trust assignments that serve as gateways to career advancement in commissioning-intensive roles. These exclusions narrow viable career pathways and may influence decisions about continued participation in commissioning work altogether. The credibility deficit cascade, therefore, illustrates how testimonial and hermeneutical injustices interact over time, transforming momentary credibility losses into durable structural inequalities.

Presence politics are predicted to intensify these dynamics. Commissioning cultures that valorise constant availability and sustained physical presence create additional credibility barriers, particularly when on-site visibility becomes equated with technical commitment. For engineers already experiencing epistemic disadvantage, these expectations compound existing credibility gaps, as their absence—whether due to work-life constraints, safety concerns, or strategic withdrawal—may be interpreted as a lack of dedication rather than as a structural constraint.

The gendered dimension of this cascade warrants particular attention. While credibility dynamics intersect with seniority and role tenure, theory predicts that gendered patterns of epistemic injustice may prove more persistent and less reversible across career stages. Gender shapes not only initial exposure to credibility deficits during commissioning but also the cumulative durability of those deficits over time. Early commissioning experiences may have disproportionate long-term effects on women’s career trajectories in technical leadership.

The credibility deficit cascade is theorised to link everyday epistemic interactions to structural career outcomes. What begins as differential recognition during a single commissioning episode can, through iterative reinforcement, reshape who is ultimately seen as a legitimate technical authority and who exits commissioning pathways. This mechanism demonstrates how epistemic injustice operates not only in discrete moments

but through cumulative processes that transform temporary disadvantage into durable inequality. Although credibility deficit cascades can affect any engineer at the margins of authority, gendered stereotypes about technical legitimacy, confidence, and risk tolerance make these cascades more persistent and less reversible for women in commissioning-intensive roles.

6. DISCUSSION

6.1 Contributions

This study makes three primary contributions to scholarship on gender, engineering work, and project-based technical practice.

6.1.1 Extending Epistemic Injustice Theory

The primary contribution of this study is the development of the Invisible Hands Phenomenon as a conceptual framework for understanding how epistemic injustice operates within engineering commissioning contexts. While Fricker's (2007) framework has been applied to professional hierarchies and institutional settings, commissioning represents a distinctive context in which epistemic injustice is predicted to unfold through rapid credibility assessments under conditions of technical uncertainty. The Invisible Hands Phenomenon theorises how hermeneutical injustice compounds testimonial injustice in contexts where interpretive resources are themselves contested. Engineers engaged in anticipatory or integrative work lack established frameworks for articulating the value of these contributions, intensifying the credibility challenges they face.

6.1.2 Commissioning as a Critical Case

This study positions commissioning as a critical case for understanding gendered engineering work, not merely another context in which gender inequalities are reproduced. Critical cases are those in which theoretical predictions are most clearly observable (Flyvbjerg, 2006). Commissioning environments exhibit the precise conditions—high visibility of technical failures, acute time pressure, distributed authority, and significant operational consequences—under which gendered credibility dynamics are theoretically expected to intensify. The concentration of these conditions in a single project phase makes commissioning an ideal site for investigating mechanisms that may be more diffuse or harder to observe in routine operations. Moreover, commissioning’s role as a gateway to senior technical positions means that epistemic injustices in this phase have multiplicative career effects. Studying project

phases discretely, rather than treating engineering work as uniform, reveals how inequalities are actively constructed through the temporal structuring of work itself.

6.1.3 Methodological Contribution

Methodologically, this study demonstrates the value of conceptual analysis in establishing research foundations for empirically neglected intersections. The systematic search confirming the absence of studies at the gender–commissioning intersection required a theoretical framework to explain why this gap matters and what dynamics might be anticipated. Rather than treating conceptual work as preliminary to "real" empirical research, this study shows that theory-building is necessary when empirical evidence is absent. Yet, the adjacent literature suggests that significant phenomena are likely at work. The synthesis of engineering commissioning literature, gender-in-engineering scholarship, and epistemic injustice theory creates an interpretive architecture that subsequent empirical work can test, refine, or challenge. This approach may apply to other under-researched intersections where theoretical grounding must precede empirical investigation.

Together, these contributions advance understanding of how gendered inequities are reproduced not only through organisational culture but through the structuring of technical work itself. This extends engineering studies by demonstrating how project-phase dynamics shape epistemic authority in ways not captured by existing organisational analyses.

6.2 Implications

6.2.1 Implications for Practice

This paper suggests several implications for commissioning practice, engineering management, and organisational equality initiatives. First, visibility should not be treated as a proxy for contribution. Commissioning leaders and project managers should recognise that anticipatory work—identifying risks before they materialise, integrating systems before conflicts emerge, coordinating across teams before communication breaks down—is both technically demanding and organisationally undervalued. Performance evaluation systems that reward firefighting or crisis resolution may inadvertently penalise engineers who prevent problems from occurring. Organisations could develop visibility protocols that explicitly document preventative contributions, integrative coordination, and anticipatory troubleshooting as distinct categories of technical work deserving recognition.

Second, credibility audits may help organisations assess whether task-allocation patterns reflect genuine capability matching or socially patterned credibility assessments. When commissioning teams consistently allocate high-visibility troubleshooting to some engineers while assigning preventative or documentation tasks to others, managers should ask whether these patterns correlate with demographic

characteristics. Simple tracking of task types by engineer characteristics can reveal whether women or other underrepresented engineers are disproportionately channelled toward less visible work. Where such patterns emerge, deliberate rotation of high-visibility assignments and explicit discussion of credibility biases may help disrupt these circuits.

Third, safety-voice mechanisms must account for credibility dynamics. Safety-critical commissioning environments require that engineers' concerns are heard regardless of who raises them. Anonymous reporting systems, structured safety debriefs with mandatory participation, and explicit protocols for responding to safety concerns can reduce the role of interpersonal credibility assessments in determining whose voice matters. Commissioning teams could implement "safety-voice accountability"—tracking not only what concerns were raised but also who raised them, who had their concerns investigated, and what follow-up actions occurred. Patterns in which certain engineers' concerns are consistently deprioritised signal potential credibility deficits requiring organisational intervention.

Fourth, attribution systems in commissioning documentation should explicitly record anticipatory and integrative contributions. Commissioning reports typically document problems that occurred and how they were resolved, creating archives that privilege reactive work. Structured documentation protocols could require teams to record risks that were prevented, integration conflicts that were anticipated and avoided, and coordination work that enabled smooth handovers. These records would create an evidence base for evaluating contributions that currently remain invisible, while also providing hermeneutical resources—shared language and examples—that help engineers articulate the value of anticipatory work.

6.2.2 Implications for Research

For researchers, this study underscores the value of phase-specific analysis in engineering work. Treating engineering practice as a uniform set of risks obscures how different project phases shape authority, recognition, and career progression. Future research should examine task allocation, credibility dynamics, and safety voice across distinct project phases—design, construction, commissioning, operations—to determine whether the patterns identified here are commissioning-specific or represent broader phenomena that intensify during high-pressure transitions. Comparative studies across project phases could reveal whether credibility deficits are consistent features of women's engineering experience or whether they concentrate in particular organisational moments.

Empirical research is needed to test the dynamics proposed in this conceptual framework. Direct observation of commissioning teams could examine how tasks are allocated in real time, whose technical judgments are questioned or accepted, and whose contributions are acknowledged in project documentation. Longitudinal studies tracking

engineers' careers before, during, and after commissioning assignments would reveal whether commissioning experience translates into advancement differently for women and men. Survey research could quantify the prevalence of strategic invisibility—whether women engineers deliberately understate their contributions or avoid high-visibility confrontations to manage credibility challenges. Such studies would provide empirical evidence for phenomena identified theoretically in this paper.

Specific mechanisms identified in this analysis warrant dedicated investigation. The Commissioning Visibility Deficit (CVD)—the organisational tendency to undervalue anticipatory and integrative commissioning work—requires measurement across engineering sectors, project types, and organisational contexts. Research could examine whether CVD operates consistently or whether particular industries, project-delivery models, or team structures mitigate this tendency. Similarly, Commissioning Risk Drift (CRD)—the process by which credibility-driven task-allocation patterns shift risk exposure and responsibility attribution—requires empirical examination. Studies could track how task allocation evolves across commissioning phases, whether certain engineers accumulate disproportionate responsibility for system failures, and how attribution patterns in incident investigations reflect prior credibility dynamics. Both CVD and CRD represent specific, testable mechanisms that can be operationalised and measured.

Finally, intervention research is necessary. If credibility audits, visibility protocols, and safety-voice accountability systems are implemented, experimental or quasi-experimental designs could assess their effectiveness in disrupting gendered task-allocation and recognition patterns. Action-research approaches could work with commissioning organisations to co-design and test interventions, documenting what works, what fails, and under what conditions change is possible. Such research would move beyond documenting inequalities to building evidence for transforming commissioning practice.

6.3 Limitations

This study develops a conceptual framework without direct empirical testing. Future research should examine these dynamics through observation of commissioning teams, analysis of task-allocation patterns, and longitudinal studies of career trajectories. While the framework is grounded in established theory and commissioning practice realities, empirical validation across different commissioning contexts would strengthen its applicability.

Second, the findings are context-specific to commissioning environments and may not generalise directly to all engineering settings. However, the aim of the study is analytical rather than statistical generalisation, offering conceptual insights applicable to similar high-risk, time-critical technical contexts.

Third, the cross-sectional design limits insight into long-term career trajectories. Longitudinal research could further examine how early commissioning experiences shape authority, retention, and leadership outcomes over time.

This study examined how gendered dynamics of credibility and authority operate during the commissioning phase of engineering projects. The analysis argues that commissioning constitutes an epistemically vulnerable environment in which task allocation, safety voice, and technical recognition are unevenly distributed, with cumulative consequences for technical authority and career progression. By making these dynamics visible, the study reframes commissioning not only as a technical milestone but as a critical site where organisational equity and safety are actively produced. This underscores the importance of examining commissioning as a formative site for understanding how organisational equity and safety are produced in engineering practice.

The conceptual model developed here provides a foundation for such studies, offering constructs and mechanisms that can be operationalised in qualitative, ethnographic, or mixed-methods research designs. In doing so, the study provides a conceptual foundation for future empirical work. It reframes commissioning as a critical site for understanding how epistemic and organisational inequalities are produced and sustained.

7. CONCLUSION

This study establishes commissioning engineering as an empirically neglected yet theoretically significant site for understanding gendered dynamics in technical work. Systematic literature searching confirmed that no peer-reviewed studies examine gender within commissioning contexts, despite commissioning's documented role as a gateway to senior technical positions and its concentration of conditions—high uncertainty, acute time pressure, distributed authority, and safety-criticality—under which gendered inequalities are known to intensify. This omission represents a significant gap in engineering gender scholarship, which has essentially treated engineering practice as uniform rather than attending to how specific project phases shape women's experiences.

The theoretical framework developed here provides a foundation for empirical research into commissioning-specific phenomena, including the Commissioning Visibility Deficit and Commissioning Risk Drift, which warrant dedicated investigation across engineering sectors and project types. More broadly, this analysis demonstrates that phase-specific inquiry can reveal how inequalities are reproduced through the temporal organisation of work itself. Commissioning is not merely another context in which gender inequalities appear, but a critical case in which mechanisms of epistemic injustice become particularly clear. Understanding these dynamics is essential not only for equity in engineering careers but for the integrity of engineering practice itself.

When credibility serves as a gatekeeper to technical authority, systems lose the benefit of diverse perspectives precisely when uncertainty and complexity make them most valuable.

Taken together, this analysis demonstrates that commissioning is not simply another technical phase of project delivery but a critical site in which gendered credibility dynamics become structurally visible. By introducing the Invisible Hands Phenomenon, this paper advances gender-and-engineering scholarship through a conceptual framework that explains how preventative and anticipatory technical work becomes epistemically marginalised in commissioning environments. The model clarifies the mechanisms through which credibility, authority, and recognition are unevenly distributed, offering a foundation for empirical studies to examine these dynamics in situ. For practitioners, the framework highlights the need to recognise and value forms of technical judgement that are easily overlooked yet essential to safe and reliable system performance. Future research should investigate how these mechanisms unfold across different engineering sectors, how they intersect with race, age, and organisational status, and how commissioning teams might redesign evaluative practices to mitigate epistemic injustice. Understanding these dynamics is essential not only for advancing equity in engineering careers but for strengthening the integrity and safety of engineering practice itself.

AUTHOR NOTE :

Companion practitioner tools and research instruments will be released separately in 2026. AI assistance was used for literature organisation and grammar refinement; all ideas, arguments, and interpretations are the author's own.

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