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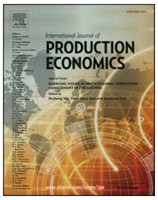

Rework in relational engineer-to-order production systems: An ‘error-as-process’ archetype

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ABSTRACT

While an extensive body of work has examined the dynamics of rework in engineer-to-order (ETO) production systems, and several archetypes to mitigate its occurrence have been produced, the role of error-making has yet to be thoroughly examined. This paper uses the theoretical lens of error-as-process to explain the rework phenomena where errors are viewed as a chain of emergent triggers, adaptive activities, and social interactions that progress and transform over time in an ETO production system. We develop a resilient error-as-process archetype-based emergent best practice to address the following research questions: (1) *How and why do errors and rework occur?* and (2) *How should a project system adapt and respond to errors and manage rework*? An inductive case study of a relational ETO production system – an AU$19.8 billion transport infrastructure project procured using a program alliance – is undertaken to examine our research questions. Through various data collection methods (e.g., interviews, documentation, and site dairies), several rework events occurring in construction are identified and analysed using our process-oriented lens. Several latent conditions (e.g., production pressure and procedural drift) and contributory factors (e.g., complacency creep and communication breakdowns) resulting in error-making and rework are unearthed. We also reveal the alliance was able to adapt and respond to errors and its rework by building resilience into its production ecosystem, as this enhanced its team and subcontractors' adaptive capacity. Our theoretically robust error-as-process archetype is grounded in the actualities of practice. It provides a frame of reference to show how relational ETO production systems should mitigate their rework. Future research is required to validate our resilient error-as-process archetype so that best practices can be identified and drawn upon to contain and reduce errors and mitigate rework in construction and other ETO production systems (e.g. shipbuilding), where relational contracting prevails.

1. Introduction

The production and operations management literature is replete with studies examining rework in various types of supply chain structures (Hayek and Salameh, 2001; Flapper et al., 2002; Flapper and Teunter, 2004; Teunter et al., 2006; Sarker et al., 2008; Gardner, 2020; Berling and Sonntag, 2022; Efatmaneshnik and Shoval, 2023; Junge et al., 2023). Six supply structures exist for production systems (Gosling and Naim, 2009): (1) buy-to-order; (2) make-to-stock; (3) ship-to-stock; (4) assemble-to-order; (5) make-to-order; and (6) engineer-to-order (ETO). In such supply chains, it is widely acknowledged that product quality can vary due to random variations in materials, operators, methods, and processes (Sofiana et al., 2019). A non-conforming product that does not meet specifications before it is distributed to customers or where problems appear later in the field may require rework or replacement (Flapper et al., 2002). Capturing non-conformances before distribution, otherwise referred to as *internal failures*, is less expensive to rectify than when they manifest in the field as *external failures* (Feigenbaum, 1991).

As observed by Zhou et al. (2022), there are “established archetypes [typical and general models of a specific system (Batista et al., 2018)] that demonstrate the dynamic properties of make-to-order/stock and assemble-to-order production planning and inventory control systems and their impact on total on-costs” (p.1), enabling performance benchmarks for a range of factors such as quality to be established. However, in the case of ETO – one/first-of-kind – production systems where products are designed and made to a specific customer order, such as

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aircraft development, infrastructure construction, and shipbuilding, well-established archetypes do not exist (Zhou et al., 2022). Indeed, these ETO production systems are not well understood as there is a propensity for them to consistently experience poor productivity, increasing external failure costs and rework (Braglia et al., 2022; Zhou et al., 2022; Chen et al., 2023). Hence, the motivation for this research. In this paper, we use error management theory to suggest, from our observations of best practice, that an error-as-event archetype, which typically prevails in practice, stymies the ability of construction organisations to adapt and respond to errors and manage rework effectively. Instead, we demonstrate that a resilient error-as-process archetype should be adopted if strides are made to contain and reduce errors and their negative impacts on construction.

A well-known example where rework within an ETO production system adversely impacts profits, share value, and the reputation of a company occurred at Boeing; its 787 Dreamliner was plagued with quality issues resulting in "low production rates and rework", which are "expected to result in approximately $1 billion of abnormal costs" (Gates, 2021). Similarly, in the ETO system of construction, rework has been identified as the most expensive waste for organisations (XYZ, 2022). For example, rework was reported to have reduced the annual profits of a Tier 1 construction organisation by 27% (Love and Matthews, 2020). Additionally, rework can be as high as 20% of a construction project's contract value (Barber et al., 2000).

Effective solutions for mitigating rework in the ETO supply chains, such as construction, are lacking as there is an absence of archetypes that can be drawn upon to understand and explain the temporal relationships, patterns, and feedback loops of errors that induce rework (Love et al., 2019a; Zhou et al., 2022, 2023). Recognising this void and the need to mitigate the effects of rework, Zhou et al. (2022) developed an archetype that merges a service-oriented design sub-system with a working-unit-orientated production system to establish an order-controlled ETO system. In doing so, the archetype can automatically control production and thus maintain lead time, enabling the system's order book to be effectively controlled and capacity requirements to be determined, offsetting the negative impacts of rework.

While the archetype produced by Zhou et al. (2022) offers a valuable theoretical contribution to our understanding of the dynamics of rework, its system boundary is limited in scope and does not consider the role of error-making that influences non-conformances and rework. This paper aims to complement the work of Zhou et al. (2022) by providing additional knowledge about error-making and rework to enable the assumptions underpinning their theoretical archetype to be broadened by focusing on real-life settings in the ETO production system of construction. In a similar vein to Zhou et al. (2022), our paper aims to address the following research questions: (1) *How and why do errors and rework occur?* and (2) considering emergent best practices, *how should a project system adapt and respond to errors and manage rework*? We deal with these questions by drawing upon a robust theoretical framing that considers the actualities of practice, enabling legitimate and informed decisions to mitigate rework to be formed and enacted.

Within the context of the ETO system of construction, we define rework to be "the total direct cost of re-doing work in the field regardless of the initiating cause, which excludes explicitly change orders [variations] and errors caused by off-site manufacture" (Robinson-Fayek et al., 2004: p.1078). Restricting the sources of rework to non-conformance only provides a fraction of the total amount that manifests in construction, but we need to recognise that they have been typically used as a *de facto* or single-point measure (e.g., Abdul-Rahman, 1995; Barber *al.*, 2000; Love and Li, 2000; Hall and Tomkins, 2001; Love and Matthews, 2020; Matthews et al., 2022a; b; Ford et al., 2023). Notably, during the production process, non-conformances are often not documented by teams working in the field, as people fear being judged by senior management for mismanaging the project (Love et al., 2018a).

Our paper commences by introducing the theoretical setting (Section 2). Next, we describe our case study approach focused on a relational delivery strategy program alliance forming part of an AU$19.8 billion transport mega-project used to address our research questions (Section 3). Examples of rework events are initially identified and described by interviewees. Then, documentary sources juxtaposed with discussions with a quality manager are conducted to ensure the validity of events before analysing the data with a process-oriented lens (Section 4). We next discuss our research's theoretical and practical implications (Section 5) before presenting our conclusions and identifying avenues for future research (Section 6).

2. Theoretical setting

Several reviews of ETO production systems exist, with Gosling et al. (2020) providing a thorough examination of their advances and emerging developments based on an examination of publications between 2010 and 2020. Additionally, for a detailed exploration of ETO production systems, we refer readers to the works of Gosling and Naim (2009), Gosling et al. (2015), Cannas and Gosling (2021), Cigolini et al. (2022), Alfnes et al. (2023), Bhalla et al. (2023) and Junge et al. (2023) to name a few.

Studies examining non-conformances and rework in ETO production systems have tended to overlook the nature of error-making. Yet human errors are typically the antecedents of non-conformance and rework, with workplace conditions influencing *why* and how they manifest in production systems (Reason, 1990, 2000; Stewart and Grout. 2001; Lei and Naveh, 2023). Without an archetype of error-making that contributes to rework, the dynamic phenomena that occur repeatedly in diverse settings cannot be identified and understood. Thus, an error-making archetype can help diagnose problem areas and be used to identify high-leverage interventions that will create fundamental change to enable the mitigation of rework.

In addressing the need for an error-making archetype, our paper, as mentioned, draws on error management theory as it provides a representation of how errors are managed in the ETO production systems of construction (Love et al., 2022a,b, 2022a,b, Love et al., 2023). Error management theory comprises two archetypes (Frese and Keith, 2015; Lei and Naveh, 2023): (1) *error prevention* (error-as-event); and (2) *error management* (error-as-process). Each archetype differs in how they view errors. Drawing on the theoretical works of Lei and Naveh (2016, 2023) and empirical observations of best practices in construction identified by Love and Smith (2016), Love and Matthews (2020), Love et al. (2019a, 2023), we develop rework-related archetypes to reflect error prevention and error management for settings that arise in the ETO production systems of construction.

Error prevention typically arises when design and construction processes are decoupled (i.e., separated), often resulting in organisations having divergent goals and objectives and the establishment of opportunistic behaviours manifesting in adversarial relations (Matthews et al., 2022a; Love et al., 2023). In this instance, a traditional view of quality tends to be espoused where the unit of analysis is the organisation (Sousa and Voss, 2002). A resource-based perspective is employed to provide a competitive advantage (Escrig Tena et al., 2001), with senior management making decisions about quality initiatives (Kaynak, 2003; Love et al., 2018a). Noteworthy, in the case of 'design and construct' and 'management contracting' procurement methods, which couple design and construction, the unit of analysis still tends to be the organisation due to an absence of mechanisms to establish collaborative behaviours (Walker et al., 2023).

When design and construction processes are coupled within a relational delivery strategy of an ETO supply chain – for example, alliancing – the features of error management, discussed in Section 2.3, materialise. The contract, called the Project Alliance Agreement (PAA), provides the basis for stimulating and incentivising collaborative behaviours, learning and best-for-project decision-making (Love et al., 2022b, 2023; Walker et al., 2023; Love and Matthews, 2024). In this situation, quality throughout the entire supply chain is considered, forming its unit of analysis (Young et al., 2001; Tzortzopoulos et al., 2020).

From an institutional/network perspective, organisations may adopt new work practices that do not directly improve their performance but their whole supply chain. The inter-organisational linkages that are established through collaboration and trust are viewed as a source of competitive advantage whereby their critical resources and routines span organisational boundaries, becoming embedded in the ETO supply chain to ensure quality and performance (Dyer and Singh, 1998; Walker et al., 2023).

Quality can be characterised in two dimensions (Sitkin et al., 1994): (1) control; and (2) learning. Effective quality management is often contingent on striking a balance between control and learning by giving due consideration to the "conflicting goals of stability and reliability and exploration and innovation" (Leonard-Barton, 1992; Mellat-Parast and Digman, 2008: p.822). Striking such a balance is a challenge for construction organisations. Control is often viewed as a default safeguard for senior management due to a mindset where 'doing things differently' is frequently deemed an unnecessary risk (Love et al., 2018a). Regardless, the accumulation and sharing of knowledge and learning (e.g., experimentation) rather than focusing on decreasing error rates (an inherent attribute of control) are key mechanisms for driving continuous improvement and innovation in volatile, uncertain, complex, and ambiguous (VUCA) environments (Sitkin et al., 1994; Linderman et al., 2004; Li et al., 2022).

2.1. *Setting the scene for error-making*

Error definitions abound in the literature and depend on the context being investigated. We refer to action-based errors in this paper, which people commit "rather than Freudian slips, linguistic errors or errors in judgement and decision" (i.e., cognitive biases and heuristics) (Lei and Naveh, 2023: p.800). Action-based errors imply a "non-attainment of a goal and non-conformity to some plan" (Frese and Keith, 2015: p.663). Such avoidable deviations can result in negative (e.g., rework, failures, and delays) and positive consequences (e.g., learning and innovation) materialising in projects (Love and Matthews, 2024).

In stark contrast to an erroneous deviation, we often see people in construction engaging in intentional (or deliberate) risk-taking (i.e., breaking the rules), also referred to as procedural violations (Reason, 1990), when performing their work to save time and money. When risks are controllable (i.e., preventable by personal action), unrealistic optimism about judgments in susceptibility can be evoked, or, to put it more colloquially, the "it won't happen to me" phenomenon tends to prevail (Weinstein, 1984: p.158). We hasten to note that it is outside the scope of our paper to examine violations even though they can interact with errors and failures and result in the need for rework (Reason, 1990; Frese and Keith, 2015; Love and Matthews, 2024; Lei and Naveh, 2023).

All forms of work during the design and construction of a physical asset, regardless of routines and activities, are faced with the probability of making an error "in which the variables are skill and frequency" (Hughes, 1951: p.320). It follows statistically that "the more times per day a [person] does a given operation, the greater the chance of doing it wrong" (Hughes 1951: p. 320). Moreover, workplace routines are mastered through repetition, as "discrete actions are translated into one coherent and automatic procedure (LaBerge and Samuels, 1974; Armitage, 2009: p.196).

It is, therefore, often assumed that more experienced people performing routines commit fewer errors than inexperienced people. At face value, such an assumption appears rational; however, it could not be further from the truth as more experienced people are prone to slips than those new to a routine due to their cognitive loading of "pre-programmed instructions (or schemata)" (Armitage, 2009: p.196). Furthermore, while experienced people are generally faster at performing procedural tasks, their actions are more closely spaced in time. Thus, they are more confusable when recalling where to resume a task after an interruption (Altmann et al., 2014). The quicker things happen, the greater the difficulty in remembering them, increasing the risk of error-making when interrupted. However, for senior managers and engineers, interruptions (e.g., requests for information, problem-solving, and resolving conflicts) to daily work activities are a norm during production on-site.

As well as the negative consequences of error-making, there are positive corollaries, namely learning and innovation. In an ETO environment where VUCA resides, cognitive failures (i.e., slips, lapses) and mistakes, collectively referred to as *active failures*, are inexorable (Reason, 1990). Yet within construction, there has been an over-zealous fixation on preventing or "eliminating errors" altogether, as the 'Get it Right Initiative' in the United Kingdom (UK) aims to achieve (see https://getitright.uk.com).

Such a prevention mindset, akin to Love et al.*'s* (2023) concept of Quality-I, however, can have the opposite of the desired effect as it can contribute to creating 'learning disabilities' in organisations (Senge, 1990) – barriers inhibiting organisational learning – that take the form of (Love et al., 2018a): (1) blocking communicative action and assessment of the environment: (2) competing demands; (3) limit learning to a single project or functional area; and (4) reducing the pool of perspectives from which experiences and lessons are drawn for decision-making. More so, these disabilities are influenced by an organisation's culture and, to a lesser degree, its leadership, which can transfer to its projects and indirectly shape the behaviour of supply chains used to deliver them (Love et al., 2018a). This backdrop provides a segue to explain how errors and rework occur and are addressed in the ETO production system of construction.

2.2. *Error prevention: an error-as-event archetype*

As we touched upon above the notion of error prevention – the mindset that predominately pervades practice in construction – assumes errors can and need to be prevented and accords with the 'error-as-event' archetype, which "conceptualises errors as *stable* events isolated in space and time" (Frese and Keith, 2015; Lei and Naveh, 2023: p.799). In this instance, as noted in Fig. 1, the context, conditions, and situations that dynamically impact patterns of error-making in projects are disregarded. Consequently, organisations focus on the end result (i.e., single-point measures) rather than the underlying latent conditions (i.e., errors at the blunt end) and context leading to the occurrence of errors, treating them as static phenomena (Lei and Naveh, 2016; Love et al., 2019a; Lei and Naveh, 2023). A case in point is the pursuit of zero errors in quality and safety.

Striving for zero error tolerance, often reinforced with slogans such as 'Zero Defects' and variants thereof, is usually embedded in the quality rhetoric of construction organisations "obdurately ascribing to *bureaucratic entrepreneurialism*" (Dekker, 2013; Love and Smith, 2016: p.4). In this instance, construction organisations claim to be making headway to attaining zero defects but simultaneously say more needs to be done, knowing all too well that this is an impossible target. Nonetheless, construction organisations continue to invest and promote zero-vision initiatives (i.e., for quality and safety) to demonstrate they actively engage in continuous improvement despite their little impact on improving performance (Zeetsloot et al., 2013; Love et al., 2018a). What is more, the forbearer of the quality movement, W. Edward Deming, dismissed the zero-vision perspective, insightfully informing us that organisations should (Hunsaker and Alessandra, 1991):

> "Eliminate slogans, exhortations, and targets for the workforce and ask for zero defects and new levels of productivity. Such exhortations only create adversarial relationships, as the bulk of causes of low quality and low productivity belong to the system and thus lie beyond the power of the workforce" (p.202).

Moving on from a focus on zero-vision, the error prevention mindset also paints people (including project teams, subcontractors, and

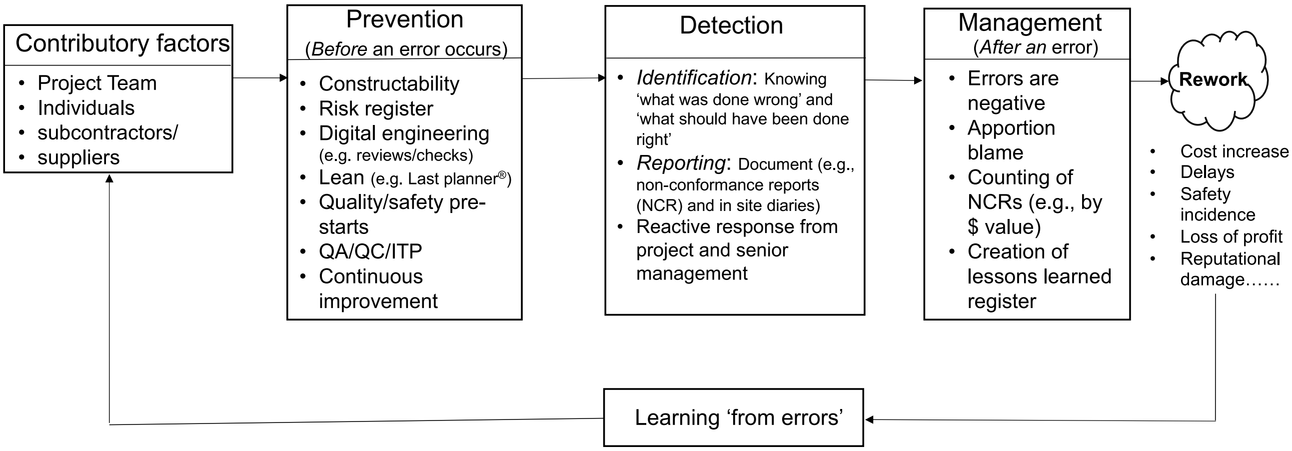

Fig. 1. Rework – error-as-event – archetype.

suppliers) as the cause of poor quality in construction (Fig. 1).

In their quest to explain poor quality, management often set out to ascertain why people make errors and attribute them to inaccurate assessments, incompetence, wrong decisions, bad judgments, and inadequate training and skill levels. To this end, people are deemed unreliable and inconsistent, undermining an organisation and its projects' rules and procedures. This position aligns with Dekker's (2017) 'Bad Apple Theory', which suggests that accidents arise due to a few 'bad apples' and that the project system would function well if not for a few unreliable people's (in)actions.

To prevent errors and rework from occurring in projects, there is a proclivity for construction organisations to put tighter procedures and controls in place, implement prescriptive tools, and overtly rely on supervisors and engineers to observe and inspect work (Love, 2020). The work practices identified in Fig. 1, sitting underneath 'prevention', for example, are typically employed in projects procured via conventional means to improve productivity (i.e., eliminate inefficiencies), manage risks, plan activities more effectively, and ensure work adheres to the standards that have been specified.

Indeed, the practices identified in Fig. 1 may prevent errors, particularly during design and engineering. Some errors will go unreported and unidentified until construction commences on-site. When errors are identified, and non-conformances arise, they should be reported and documented. Still, as we mentioned above, there is sometimes a reluctance to do so as the response tends to be reactive as a blame game is triggered, especially if an event is major. In this instance, quality is measured by the cost impact of non-conformances on a project's bottom line, with a lesson learned register being formulated at practical completion to demonstrate an organisation's supposed commitment to continuous improvement. Since lesson-learned registers based on non-conformance events are invariably token gestures, they seldom result in changes in practice needed to ensure the mitigation of rework in future projects (Love et al., 2019b).

2.3. *Error management: an error-as-process archetype*

While there is an appetite for error prevention to occupy the mindset of the ETO production system of construction delivered via traditional means (e.g., design-bid-build), within collaborative procurement environments such as those based on an alliancing, error management preponderates (Love et al., 2023). Error management assumes errors happen, and there is an acceptance they will arise. So, error-making forms an integral part of our daily work and is needed for learning and innovation (Reason, 1990; Frese and Keith, 2015).

The concept of error management takes place after errors have occurred and thus "attempts to block their negative consequences or to reduce their adverse impact through design or training" (Frese and Keith, 2015: p.665). The organisational practices of error management identified in Fig. 2 are (Van Dyck et al., 2005): (1) communicating about errors; (2) sharing error knowledge; (3) helping in error situations; (4) detecting errors quickly to minimise adverse impact; (5) analysing errors; (6) coordinating error handling; and (7) effective error handling in construction settings. Such practices have been found to exist in ETO supply chains procured using an alliancing delivery method juxtaposed with facets of resilience, namely, flexibility and opacity, leading to the formulation of a 'resilient error-as-process archetype' in Fig. 2 (Love and Matthews, 2024; Love et al., 2024).

In this archetype, errors are attended to as quickly as possible to limit their adverse impact. The coping process ingrained within error management aligns with Wildavsky, 1988 view of resilience, which is defined as the "capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back" (p.77). Resilient organisations can absorb and proactively respond to a "discrete environmental jolt" (Williams et al., 2017: p.740).

After adapting and responding to a rework event, organisations can learn and implement strategies to prevent errors from occurring in the future. By enacting the process of *requisite imagination,* organisations can anticipate 'what might go wrong' while planning activities in projects based on previous experiences and knowledge through learning (Westrum, 1991). To this end, *foresight, coping,* and *recovery* become embedded in the archetype.

The error-as-process archetype provides a robust theoretical foundation for capturing and representing the temporal dynamism of errors in production systems (Lei & Naveh, 2016, 2023) and epitomises emergent best practices for managing errors and rework in construction (Love et al., 2019a).

Error management was initially developed as an add-on to error prevention and a way to handle errors better (Frese, 1991). However, despite the perceived benefits of using error management as an addition to error prevention, studies examining whether they individually or both contribute to producing beneficial outcomes for organisations have been limited (Van Dyck et al., 2005; Dimitrova et al., 2017; Love et al., 2022a, 2022b, 2022c; Matthews et al., 2022a). In a controlled environment, error prevention has been found to have "negative effects on cognition and adaptive transfer performance" and error management "alleviates worry and boosts one's perceived self-efficacy" (Dimitrova et al., 2017, p.658). Here cognition refers to on-task thoughts and negative self-related off-task thoughts. "On-task thoughts are defined as directed attention towards a specific task" whereas "off-task thoughts involve disengaging attention away from goal-directed action" (Dimitrova et al., 2017: p.660)

Likewise adaptive transfer performance involves using one's existing knowledge base to change a learned procedure or generate a solution to a new problem (Ivancic and Hesketh, 2000: p.1967).

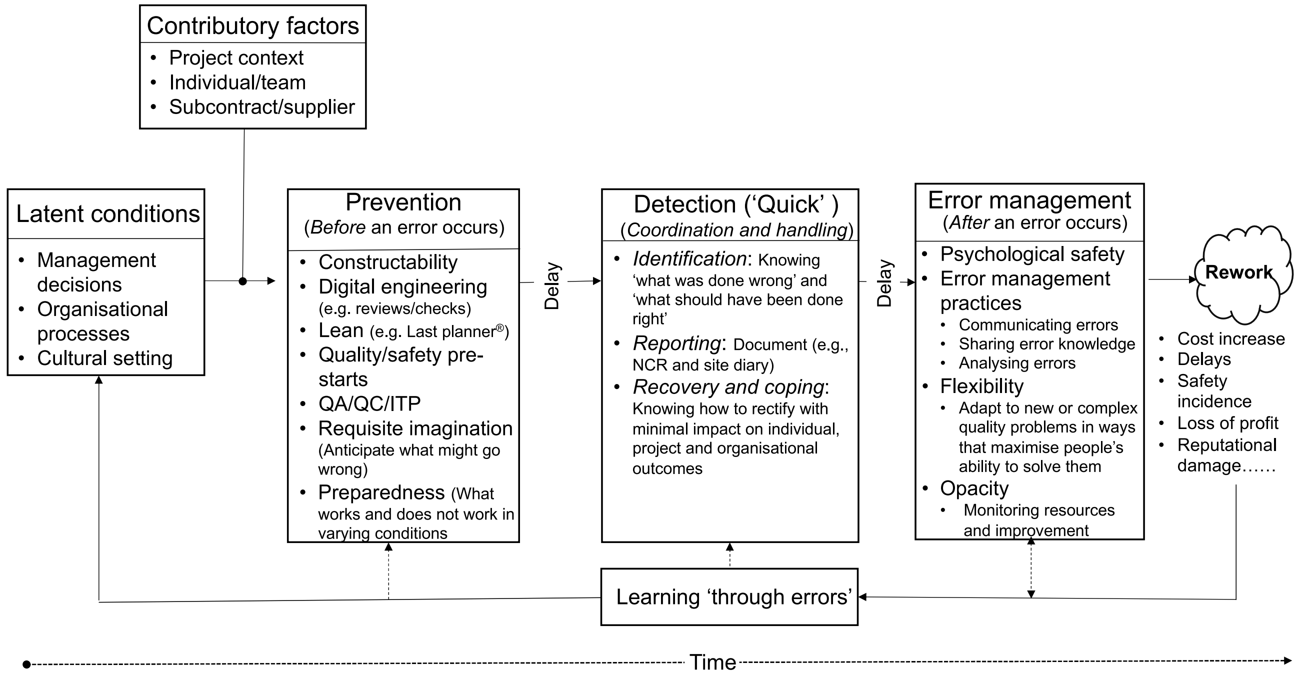

Fig. 2. Rework– a resilient error-as-process – archetype.

Within the context of the ETO production system of construction, Love et al. (2022c) have shown that error management (i.e., positive) and error prevention (i.e., negative) are contradictory to one another in their effect on reducing rework in projects. When an error prevention mindset prevails, people worry about making errors, which is counterproductive to creating psychological safety in teams. However, psychological safety is critical to employee well-being and enhancing employee voice and commitment, which alliance procurement models aim to harness and incorporate into their project culture (Love et al., 2019a; Love and Matthews, 2024).

In Fig. 2, we present a resilient error-as-process archetype reflecting the practice of a relational ETO production system in construction, with error management taking a pivotal role in containing and reducing errors (Love et al., 2019a, 2019b, 2023). An error-as-process archetype views errors as a "cascade (or chain) of emergent triggers, adaptive activities, and social interactions that develop, change and travel through a [project] system over time" (Lei and Naveh, 2023: p.798). Thus, errors are not static events within ETO supply chains; they are dynamic and change over the life of a project (Zhou et al., 2023).

The error-as-process archetype does not view errors as a cause of an adverse event – a commonly held belief of an error prevention mindset – but rather a consequence. Such consequences have "their origins not so much in the perversity of human nature" but instead in the latent conditions generated by management decisions (influences) and the organisational and social processes that make up the culture of a workplace, influence the design of equipment, standards, or systems, and underlie supervisory inadequacies (Reason, 2000: p.768; Love, 2020).

The latent conditions residing in an ETO supply chain can result in error-provoking conditions within projects (e.g., production pressure, understaffing, inexperience, stress and fatigue, and inadequate equipment). In addition, latent conditions can contribute to *procedural drift*, whereby a mismatch between procedures and practice occurs in an organisation's projects, weakening its effectiveness in capturing errors (Dekker, 2017). Over time, this mismatch can amplify, widening the gap between how a project's systems were designed and how they work (Reason, 2000; Dekker, 2017). When production pressure is present in projects, which is often the case in construction, people may stray from their regular routines to make work more efficient, particularly when multiple goals need to be accommodated (Reason, 1990; Love et al., 2018b).

As the term suggests, latent conditions lie dormant within an ETO production system for some time before they combine with active failures (i.e., errors at the sharp end of production) and local workplace triggers unique to a project's context to create a rework and/or a safety event (Reason, 2000; Love et al., 2019a). Put simply, active failures are acts or conditions that precipitate the event situation. The consequences are immediate and can often be prevented through design, training, operating standards, systems, and adhering to best practices. In contrast to active failures, "whose specific forms are often hard to foresee, latent conditions can be identified and remedied before an adverse event occurs" (Reason, 2000: p.769).

Often, errors materialising during the engineering process are only identified once work has begun on site or even during the operations of an asset. A similar situation arises with errors when work is performed in the field. While engineering errors, for example, may initially go unidentified and have no immediate effects, they may interact with prevailing latent conditions to trigger an event requiring rework or even a major failure (Lei and Naveh, 2023). So, if construction organisations can understand and acquire knowledge about why and how latent conditions, active failures, and workplace triggers interact to generate rework, they can take a proactive rather than reactive approach to managing risk and uncertainties associated with rework.

3. Research approach

To recap, there is a need to develop a theory of rework causation to explain why it manifests in ETO production systems, enabling the means to bring about the changes in practice to mitigate its occurrence (Love et al., 2024). Thus, adopting a resilient error-as-process archetype lens, our paper aims to explain how and why errors and rework occur and how a project system should adapt and respond to their occurrence. From a methodological viewpoint, the research focuses on a case study, a project procured using a program alliance – a relational delivery strategy – underpinned by a PAA. We employ an interpretative case study approach to obtain a broader appreciation of rework by undertaking a multifaceted exploration within a real ETO production system (Stake, 1995).

3.1. Case selection

The case was selected pragmatically as the project, comprising five individual program alliances, had been experiencing significant levels of rework. As a result of research undertaken with the Barwon Water Program Alliance (Love et al., 2023), we were invited by one of the five programs to examine why and how rework was occurring and provide suggestions to mitigate its occurrence. We were invited to join the alliance's continuous improvement team and participate in their meetings over three years. The project is also unique. It seeks to transform a major Australian city's transport infrastructure and network. The State government's representative agency responsible for delivering the project aims to stimulate continuous improvement and innovation so best practices can be generated and shared with the broader construction industry to improve its performance and productivity.

While the selected project is unique in its aim and context, program alliancing in its various guises is a popular delivery strategy used by the Australian public sector and in other countries, such as Finland and the Netherlands, to procure infrastructure projects when they are complex and scope is difficult to define (Scheublin, 2010; Lahdenperä, 2012; Hietajärvi and Aaltonen, 2018; Walker and Rowlinson, 2020). Thus, the experiences garnered from this case offer learning opportunities to enhance the performance and productivity of a relational ETO production system of construction.

3.2. Case description

The transport mega-project's current contract value is AU$19.8 billion, but this cost is expected to increase due to changes in scope. The project was established in 2015, and its portfolio of works is scheduled to be completed by 2030. A production mindset drove the decision to adopt a program of works to develop and deliver assets rather than a single bespoke project approach.

The total allocation of work packages (or projects) to an alliance provides certainty and continuity of work. It thus attracts and retains large-scale, high-performing teams, and that fosters continuous improvement. Moreover, this certainty and continuity of work enable an alliance to invest in skills development, establish long-term supply chain agreements, create safe and healthy working conditions, design standardisation, and reuse.

Using a program approach allowed the State government's representative authority to 'slice up' the mega-project into smaller, more manageable packages. The upshot is that greater emphasis can be placed on front-end engineering, planning, and development, augmented by the delivery model's collaborative nature. The project's commercial and governance frameworks incentivise performance in key areas such as continuous improvement, innovation and safety, community engagement, sustainability, diversity, and social procurement.

Our research focuses on one of these alliances as our unit of analysis. The alliance included four organisations: (1) a constructor; (2) two design partners; and (3) a rail network operator. As of January 2024, the alliance had completed seven projects, with an additional two in progress being made available, which include the removal of existing and the construction of new road and rail infrastructure. For reasons of confidentiality and political sensitivity, we cannot provide any more details about the project.

3.3. Data sources

Various data sources were collected from the seven completed projects. We initially conducted 19 semi-structured interviews with alliance members designed around key constructs identified in Fig. 2. Moreover, these constructs are mapped to our interview questions identified in the Appendix. Interviewees were purposefully selected from the functional areas of the alliance (such as engineering and design, delivery, and commercial) along with the operator and subcontractors to garner a broad understanding of how errors are managed and why rework manifests from varying viewpoints (e.g., *how*, *why*, *what,* and *when*).

We set aside three months to conduct the interviews. A total of 30 interviewees were invited via email to participate in the study, with all agreeing to be interviewed. Only 19 interviews, however, were conducted within the time frame. Prospective interviewees were unable to find time in their busy schedules to accommodate an interview at the agreed and allotted time. However, data saturation, particularly within the context of identified rework examples, began to emerge with additional data about events contained within the project's documentation. The interviews ranged from 30 to 60 min and were digitally recorded. Then, the interviews were transcribed and sent to each interviewee to check and amend if necessary to approve them for analysis.

We also had access to documentation and a quality manager to help us acquire further insights into the rework events identified by interviewees and help us craft a narrative to address our research questions and ensure triangulation (i.e., to test the validity of events through the convergence of information from different sources). The documentation available was non-conformances (>300 reports), inspection test plans, lessons learned reports (>500 entries from the seven projects and an additional two that were in progress), internal/requests for information (i/RFI) (>2000), site dairies (e.g., daily reports >5000 records), and issues for construction (IFC) documentation (e.g., drawings). Notably, the documentation pool increases daily as the alliance designs, engineers, and constructs new projects.

3.4. Analysis

Fig. 3 presents the process used to collate data and conduct our analysis, which was conducted in three phases. As mentioned above, interviews were used to identify rework events and understand their occurrence from the interviewee's perspective (Phase 1). We then searched the NCRs, i/RFIs, site dairies, and IFC documentation made available through 'Team Binder' – a cloud-based documentation management solution – for further information about identified rework events to gain insights into how the project system adapted and responded to them (Phase 2). The transcribed interview manuscripts were inputted into NVivo 12, and the documentation (e.g., nonconformance, site diary, photographs, i/RFI, RFI, and drawings) relating to the rework event was accordingly tagged to the events identified by interviewees and used in our analysis (Phase 3).

We used *deductive thematic analysis* (Braun and Clarke, 2022) with the feature descriptions of our 'error-as-process' archetype in Fig. 2 as our first-order themes (FoT). Second-order themes (SoT) emerged from our interpretation of the events, acting as a descriptor to help provide additional meaning to why the rework events unfolded and how error management practices were deployed.

4. Research findings

For all interviewees, the alliance was the first time they had been involved with delivering a program of works using a relational procurement strategy. All interviewees believed that the amount of rework experienced in the alliance's projects, with a caveat that they did not know its costs, was considerably less than others they had been involved with delivering. Unlike conventional procurement approaches, the alliance's contract is underpinned by a PAA specifying all parties' behavioural requirements and expectations (e.g., no blame, risk-sharing, collaboration, and best-for-project outcomes). The PAA mitigates opportunistic behaviours, information asymmetry, adverse selection, and moral hazards, which can act as latent conditions in ETO supply chains procured via conventional means.

Since completing the first of seven projects, the alliance has observed

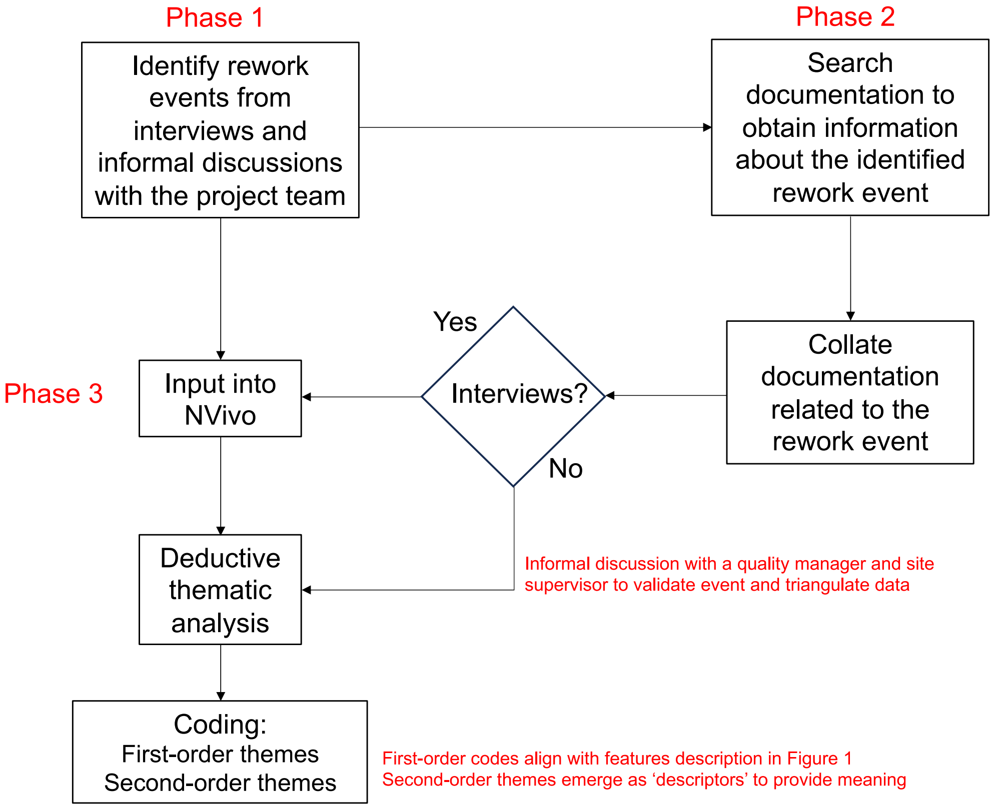

Fig. 3. Research process.

that the number of non-conformances requiring rework has diminished during construction. Notably, several additional projects are planned or underway. Indeed, lessons have been learned, and strides have been made to mitigate rework resulting from design changes and errors by the alliance. For example, standardising and re-using design components through developing an 'adopt, adapt and innovate strategy' optic resulted in marked improvements in constructability and productivity during construction.

Design standardisation helped the alliance adapt and respond to the production pressure placed upon them by the State government, stemming from the drive to deliver projects and demonstrate their benefits to businesses and communities as soon as possible. Exacerbating the production pressure was the shortfall in skilled and experienced people and a transport infrastructure boom within the State, stimulated by an increasing need to address traffic congestion, ageing assets and networks, and growing passenger and freight demands.

Several other transport infrastructure mega-projects were simultaneously constructed in the Australian city where the project was being delivered. Hence, employment opportunities were plentiful. Yet the production pressure arising from the case study project placed considerable job strain on the alliance's workforce and stretched the capacity of its supply chain. Due to job demands, staff retention in the alliance became an issue – under-resourcing became an ever-present reality – as employment could be readily sought elsewhere. Similarly, the alliance's supply chain capability and capacity were stretched as labour and materials were in short supply due to COVID-19 and the war in Ukraine.

To adapt and respond to the conditions imposed on the alliance from production pressure, it sought to assuage effects by: (1) providing a flexible hybrid working arrangement (a mix of office/site and home/remote based working) for alliance team members; (2) utilising digital engineering technologies during engineering design and in construction to acquire productivity gains; (3) training and upskilling their supply chain (e.g., quality, safety and environmental systems); (4) providing continuity of work to key supply chain participants such as civil contractors and incorporating their involvement into the engineering process; (5) establishing an error management culture, albeit unconsciously as a result of the PAA (see Love et al., 2022c Matthews et al., 2022a; Walker et al., 2023); and (6) fostering an environment of psychological safety in the alliance and throughout its supply chain. In this case, people (and organisations) were encouraged to speak up freely and comfortably without fearing negative consequences to present ideas, raise questions and concerns, and identify and share mistakes. Psychological safety was a precursor to stimulating the adaptive and innovative performance of the alliance, enabling it to acclimatise to the prevailing production pressure and thus deliver best-for-project outcomes.

We have provided an overview of the context within which the alliance is constructing its projects. Regardless of the alliance's efforts to reduce non-conformances and address production pressure, errors naturally occurred, requiring rework to be performed. We now present the findings for our first research question – why and how errors and rework occur – using a process-oriented lens, as depicted in Fig. 2.

4.1. Rework: a resilient 'error-as-process' explanation

Our operational definition of rework, identified above, excludes change orders and off-site manufacturing errors. We selected four events identified by interviewees to address our first question, which seeks to understand why errors and rework occur. The selected events are: (1) a mechanical plinth; (2) a road bridge beam; (3) U-trough reinforcement stitches; and (4) a PVC pipe in a drainage pit.

These rework events did not adversely impact project performance individually, with costs varying between AU$500 and AU$2000. Perhaps the most significant rework event is related to constructing architectural screens attached to a bridge over a road, providing protection from weather and acting as a safety barrier. Here, a design error went unnoticed and resulted in the screens being dismantled, their connection details re-fabricated, and then reinstalled at the cost of AU$ 616,000. This specific rework event, juxtaposed with several others, had a significant cost impact during the alliance's early projects, as detailed in Love and Matthews (2022).

Incidentally, each rework event to be analysed was issued with a non-conformance. However, as we have pointed out, errors are often handled using informal means and thus not documented in an NCR. For example, in a site diary, a reference was made to damaged drainage pipes requiring replacement. In this instance, a project engineer had organised all the necessary drainage pipes forming part of the subcontract work package to be brought to and stored on-site to reduce travel costs and save time.

The drainage pipes lay dormant on-site for over three months until they began to be used. But during this period, they had to be moved six or seven times as work progressed, with several being damaged and having to be replaced. Unfortunately, the damage to one pipe went unnoticed until it had been installed. Naturally, the pipe had to be substituted and replaced with one that conformed, resulting in the need for rework.

Referring to the four rework events in Table 1, which we summarised and framed as per the feature descriptions around the FoT of our resilient error-as-process archetype, we can see SoT such as production pressure, procedural drift, limited resourcing, and lack of supervision provide the latent conditions from which rework was required. While the latent conditions that were identified almost always impact ETO production systems, the contributory factors (i.e., active failures) manifest from the context of practice, with each event in Table 1 being unique to each project. However, *complacency creep* (i.e., the false sense of security that develops when someone takes shortcuts without considering the negative consequences of their (in)actions) was explicitly present. It was also a recurring theme identified by interviewees. As soon as an error was identified, the alliance team and subcontractors sought a solution to mitigate its effects. Resolving errors was a collaborative effort, with a preoccupation of safety vigilance at the forefront of the planning process to perform the required rework.

Expressing their opinion on why complacency creep occurred, a supervisor suggested that the pace of construction often meant people's response to job demands was to switch on their "auto-pilot" to get work done and cope with the stress. Thus, people became habituated to not adhering to procedures. But equally, before each of the four events was identified, the importance of adhering to procedures from peers was not reinforced or reiterated. Acknowledging this problem, a construction manager made the following comment:

> "We had assumed project engineers would double-check levels [RLs] and follow the concrete pour checklists. But then I didn't make this clear to them. I guess some of them are inexperienced. After the incident with non-conforming piles, we reinforce the importance of our checklists".

Adding further context to this issue and referring to an example occurring in the alliance's first completed project, a quality manager stated:

> "We just finished asphalting the rail stabling yard at [XXX], and the sub-contractor came in to cut the concrete ready for the sealant joints. But they weren't properly supervised and ended up cutting the rail head. Well, they cut deeper than they should have. They had to do repair and additional welding, costing about $40,000. We raised an RFI to propose a rectification methodology. An NCR was also raised and went to [the rail operator] for approval, which took 2–3 weeks. The project engineer should have marked the location to cut it, but instead, they presumed that the sub-contractor would know. Many issues arose due to the engineers not giving clear direction to sub-contractors; they were inexperienced in giving instructions. Senior project engineers are too busy to train them and didn't bother performing checks".

Mindful of the dangers of not reinforcing expected behaviours and complacency creep and copycats normalising deviance, supervisors have introduced 'quality guides' into toolbox talks and daily construction meetings to guide, bolster and normalise required actions. Underpinning the importance of assuring quality, a site supervisor remarked:

> "I run a daily 2:00 p.m. coordination meeting with the entire site team, including subcontractors. We sort of run through the works of the day and discuss any quality problems [errors and rework] that may have happened or could have happened. So, we have a look at how we have gone so far. And what does tomorrow look like for the next couple of days?".

As an understanding of why and how errors and rework occur has been garnered, we now focus on addressing our second research question, which concentrates on how the alliance adapts and responds to errors and rework.

4.2. *Adapting and responding to errors and rework*

In this section of our findings and analysis, we address our second research question, which aims to determine how a project system should adapt and respond to errors and manage rework. How the alliance adapted and responded to errors and managed rework reinforces the resilience aspect of the features identified in our archetype. In doing so, we demonstrate how a project should go about addressing its errors and managing rework in construction.

Given the complexity and unpredictability surrounding error-making, process reliability is neither entirely achievable nor desirable, a widely voiced and accepted position among interviewees. As such, the PAA enabled collaborative behaviours to be nurtured throughout the alliance with a mindset that 'errors happen' to be extended to the sharp end of production. Describing the culture of the alliance, a design manager referred to it as a "just culture", making explicit its no-blame environment. In a similar but more descriptive framing, a subcontractor specialising in civil works implicitly described the alliance's culture in terms of its awareness to build capacity (e.g., upskilling and improving knowledge), acceptance of mistakes and 'learning through errors' (i.e., how to handle them) to enact continuous improvement making the following remark:

> "The alliance has supported us when we've made a mistake. They've helped us improve the capability of our quality and safety systems. We often share our rework experiences with the alliance, and if we have a near-miss, we share this as well. We have established a relationship with them [the alliance] and have skin in the game. So, we share our knowledge as it benefits both of us".

The alliance adapted and responded to errors by encouraging site management teams and subcontractors to communicate errors immediately and work together to solve the problem. No organisation wants to be responsible for paying for the costs of rework. However, the alliance espoused the need to take accountability, which was done by accepting the errors made while maintaining the condition to 'get it right the first time'. For example, in the events we identify in Table 1, except for the 'U-Trough Stitches' where the supplier erred, the alliance bore the costs of rework – it was their responsibility to do so. The effective two-way feedback after each event helped solve problems quickly and facilitate learning and trust.

As the alliance had existed for several years, it was able to build resilience into its production ecosystem to enhance its team and subcontractors' adaptive capacity. This resilience was achieved by strengthening its capacity to cope with process variability by developing a mindset to understand 'why things go wrong' and 'why things go right'. For example, at daily construction meetings, supervisors would seek the views of the project team about how work was proceeding, asking them to specifically explain 'what went well' and identify problem areas. A similar process is applied to daily pre-start meetings with subcontractors.

An example of how the alliance demonstrated its resilience by

Table 1
Error-as-process lens to explain rework.

'Error-as-Process' Feature Description (FoT)	Mechanical Plinth	Road Bridge Beam	U-Trough Stitches	PVC Drainage Pipe
Cost of rework	$1500	$2000 (proposed)	$1500	$500
Latent Conditions (LC)	***LC-SoT-1:*** *Production pressure*: The schedule was optimistic and driven by production pressure, and the concrete pour had been scheduled – it could not be delayed as the slab to be poured was on the project's critical path. ***LC-SoT-4***: *Limited resources*: Lack of available engineers to perform pre-pour inspection checks	***LC-SoT-2:*** *Lack of supervision*: The precast (foreperson) supervisor did not provide adequate supervision. A worker had not been informed that the reinforced projection strands needed to be cut at 680 mm, not 100m. In previous projects, they were cut to 100m. In sum, miscommunication resulted in the error occurring.	***LC-SoT-3:*** *Procedural drift*: The concrete supplier's procedures were not followed, so incorrect-sized steel fibres were supplied. Thus, 35 mm instead of 60 mm steel fibres have been included in the concrete mix. The non-conformance was identified as a repeat event.	***LC-SoT-1:*** *Production pressure*: Late design change to the gradient of an underpass ramp. Work commenced on-site, and a design review was overlooked due to pressure to issue IFC. A procedure was in place but ignored. There was an assumption levels were correct
Contributory Factors (CF)	***CF-SoT-1:*** *Inexperience*: The surveyor's experience with using a laser was limited. The project engineer did not check the laser results and assumed they were correct (. The slab at the north end of the slab, as denoted in the supplementary file, was poured correctly. The engineer had to multi-task. Thus, tasks were prioritised, and a pre-pour check was not performed – they assumed the reduced levels (RLs were correct, like the north end. The NCR reported that there was a 'miscommunication'.	***CF-SoT-2:*** *Complacency creep*: The precast subcontractor provided precast beams for several projects. In this case, the specification had been slightly amended. The QC procedures had not been followed – *complacency creep* manifested.	***CF-SoT-3:*** *Communication breakdown*: The concrete supplier's customer service representative ordered the wrong sizing steel fibres. The representative copied details from a previous order (complacency creep) The contractor's project engineers did not notice the discrepancy between the docket and IFC drawings. It was assumed what was delivered was correct. No 'formal' procedure is in place to check deliveries against specifications. However, 60 mm, not 35 mm, has been ordered and confirmed by the concrete supplier	***CF-SoT-1:*** *Inexperience*: Clash detection within a building information model for services was not performed. An engineer needed more experience and time to accomplish this task, as the IFC drawings needed to be provided to the construction team. The drainage subcontractor had limited experience with digital models and thus relied on CAD-based drawings. See the 'as built' in the supplementary file. The project supervisor was stretched and did not liaise with the drainage subcontractor before the commencement of work
Prevention (P)	***P-SoT-1:*** *Complacency creep*: Quality Control. Quality control procedures were in place but only adhered to in a piecemeal way – not applied consistently.	***P-SoT-2:*** *Communication breakdown:* The precast supervisor did not follow the QC process even though a well-oiled procedure had been established in the precast yard. The supervisor had been distracted by an issue.	Internal processes of concrete suppliers were not available for examination.	***P-SoT-3:*** *Misinterpretation* QC/ITP: Failed to notice that a 225 mm PVC pipe entering a drainage pit had been installed 0.167 mm below the designed inlet level. The pipe was installed below the inlet to avoid clashing with an electrical conduit. It also did not conform to the road authority's required standards.
Detection (D)	***D-SoT-1:*** *Inspection* An inspection of the slab by an engineer after the concrete pour revealed that the starter bars were 30 mm too low and that the upstands had collapsed. During the pour, the upstands were stood on, resulting in them being damaged.	***D-SoT-1:*** *Inspection* The precast supervisor inspecting the beam issued a non-conformance and notified the contractor immediately of the error that had been made. An i/RFI was raised by the contractor explaining to the designer a non-conformance had occurred: a projecting strand was cut at 100 mm instead of 680 mm for Beam G11. They also proposed a solution utilising a double-end coupler.	***D-SoT-1:*** *Inspection* An inspection of the concrete mixture revealed that it was mainly comprised of 35 mm steel fibres. Poured concrete was also checked for concrete spans (i.e., 1 to 3, 6, 7, and 13). Evidence of 60 mm was identified at the top of the stitch. Once project engineers identified the issue, part of the span had already been poured. A decision was made to continue with the span's pour to avoid cold joints forming. The concrete supplier's technical manager and supervisor were notified of the problem but could not source the correct 60 mm steel fibres. Five stitch pours had to be cancelled. An i/RFI was raised to seek advice from the designers on how to proceed. The work was accepted 'as is' because it would be repaired if cracks >20 mm occurred. This same situation and solution had happened on a similar project. Cracks did eventuate, and rework was required.	***D-SoT-1:*** *Inspection* An i/RFI was raised by a project engineer after work had been inspected, requesting how work should proceed. The 'designer's' response was "no objection to the DN225 inlet to D03-10 being lower as the pit D03-10 IL is deeper". On receiving the advice, a non-conformance was issued.
Error Management (EM)	***EM-SoT-1***: Detecting quickly to minimise adverse impact: As soon as the errors were identified, the project engineer, subcontractor, and designers were together quickly to develop a solution so as not to delay the project.	***EM-SoT_2:*** *Communicating errors*: The solution proposed by the precast subcontractor had not been seen before by the contractor's supervisor and project engineer. However, the designer stated 'as-is' as the strength	***EM-SoT-3***: Sharing error knowledge: The non-conformance had been previously raised on another project. The non-conformance was shared with the entire project team, and a protocol	***EM-SoT_2:*** *Communicating errors*: Communication of the error to the design team suggests that clash detection should be performed before issuing IFC drawings. Also, sharing of errors via the alliance's

(*continued on next page*)

Table 1 (*continued*)

'Error-as-Process' Feature Description (FoT)	Mechanical Plinth	Road Bridge Beam	U-Trough Stitches	PVC Drainage Pipe
	Within two days, the error was rectified. The solution was to drill and epoxy new 'L' bars for the plinth with 150 mm embedment into the concrete with a 300 mm leg length. In the case of the upstand, new U bars were drilled into the slab and epoxied with 150 mm embedment (See annotation in the supplementary file). A thorough check of levels is to be performed by several people during the pre-pour to ensure all levels are correct and the appropriate RLs are used. This requirement was reinforced at daily construction meetings before concrete pours were undertaken. Resources will be available for checking levels and identified as a risk.	of the beam was not compromised. After the error occurred, it was communicated and shared with the project team via a toolbox meeting. The solution enabled the work to progress without delay and with minimal cost. Other projects were notified of the solution.	was developed to verify orders on-site before concrete pours were made to prevent this from happening again.	intra-net so other projects can be forewarned of the potential' error trap' that may arise when installing drainage.

adapting and responding to the reinforcement for a concrete structure incorrectly installed is presented in Table 2. In brief, splices/cogs alternated between bars in one direction according to the IFC drawings.

Nevertheless, the Australian Standards required that splices/cogs needed to alternate in both directions. The IFC drawings were incorrect. An error of this ilk should have been picked up during the design review process. We have been unable to identify why the error occurred during the design review. However, we rely on the engineering manager's testimony suggesting that design and construction activities had been 'fast-tracked', so there was a burden to produce IFC drawings to meet on-site scheduled works. We can only assume, based on an engineer manager's evidence, that the error transpired due to the misapplication of an engineering rule (i.e., rule-based mistake), as the requirement to adhere to Australian Standards had gone unnoticed, with preference given to that specified by the asset owner.

5. Discussion

It can be gleaned from the findings we have presented using our process lens that several latent conditions (e.g., production pressure, limited resources, and procedural drift) and contributory factors (e.g., complacency creep and miscommunication) explain why and how error-making and rework manifested in the projects delivered by the alliance. We also revealed the alliance was able to adapt and respond to errors and its rework by building resilience into its production ecosystem, as it enhances its team and subcontractors' adaptive capacity. Indeed, production pressure, workforce shortages, financial constraints, and the procurement approach have been repeatedly identified as latent conditions that can influence error-making in an ETO production system of construction and adversely impact its performance (Alexander et al., 2019).

Commercial and contractual assumptions often underpin major infrastructure projects and preclude fostering collaborative relations between organisations and providing performance incentives (Gosling et al., 2020). Consequently, opportunistic behaviours and the blame game flourish, often resulting in projects becoming a series of islands where only the contract-savvy organisations benefit from successful claims and disputes over errors and rework. It is these behaviours and corresponding actions that a relational ETO supply aims to eradicate. In doing so, the cacophony of conditions and situations contributing to rework associated with conventional procurement practices dissipates (Love et al., 2024). This is not to say that relational ETO supply chains are a panacea for mitigating rework. Still, they are better positioned to contain and reduce errors in construction.

With the environment of major infrastructure projects becoming increasingly uncertain and complex and latent conditions becoming exacerbated, their risk of mis-performance increases exponentially. In acknowledgement of this problem, the response of several public sector agencies, particularly in Australia and the case study we present in this paper, has been to place importance on building resilience into their supply chains by engaging in relational-based procurement, such as alliancing to share risks, better manage uncertainty and ensuring best-for-project outcomes are delivered (Walker and Rowlinson, 2020).

The contractual and commercial conditions and requirements, underpinned by the PAA, explicitly set out the expected (collaborative) behaviours of the organisations forming the alliance entity and the corresponding financial incentives for meeting and exceeding project deliverables. Thus, an aspirational focus is 'designed-in' to an alliance's delivery strategy, providing an impetus to engender continuous improvement, learn, embrace innovation, and mitigate rework (Walker et al., 2023). Rather than 'learning from errors', the alliance presented in this paper developed a capacity to 'learn through errors' by working with its subcontractors to: (1) resolve problems quickly; (2) mitigate the adverse consequences of errors; and (3) enacting the appropriate changes to practice so future reoccurrences of error can be averted.

Juxtaposed with the alliance's organisational error management and resilience practices, which have taken several years to nurture and effectively implement, it has now developed the capability to understand, adapt and respond to its errors and minimise the impact of rework. Notably, the program alliance's duration – eight years to date, with another seven until completion – has been critical to fostering its error management culture, which has an integrally intertwined role within its continuous improvement and innovation strategy. This starkly contrasts with ETO supply chains procured using conventional means, which are considerably less in duration and struggle to learn and innovate.

Consideration needs to be given to the context of errors and rework to explain why and how events unfolded. However, as shown in Table 1, explanations for rework causation are inexorably multifaceted. Thus, the direct cause-effect condition often used to explain how one event causes another to happen – rework causation – cannot be relied upon due to the nuances of the context and situation within which errors occur. Hence, we introduce the importance of a resilient error-as-process archetype lens.

While errors are unpredictable and cannot be eliminated, people's behavioural patterns can provide insights about the contributory factors and the situations where they occur. For example, the relational ETO production system we have examined in this study indicates that

Table 2
Resilience in action: Adapting and responding to error and rework.

Situation: At a pre-start meeting, a supervisor explained to subcontractors that a significant concrete pour was planned late that afternoon. However, during a pre-pour inspection, it was observed that the reinforcement's layout for a concrete structure did not conform to Australian Standards but had been installed in accordance with the IFC drawings and specifications. The supervisor raised an i/RFI on a Friday afternoon to determine whether the installed reinforcement layout could be left 'as is'. The response to the i/RFI was that the reinforcement needed to abide by Australian Standards and not what was specified and installed. The consequences of this situation were added pressure on the subcontractor, additional materials, and the potential for safety incidents. The cost of rework was AU $20,000, and the concrete pour was delayed by a week, though the project's scheduled completion date was not impacted.

Resilience Element	07:00 Monday *Foresight* The ability to predict something bad happening.	12.00 Monday *Coping* The ability to prevent something bad from becoming worse.	17:00 Monday *Recovery* The ability to recover from bad once it has happened.
Individual	The supervisor called the structural engineer requesting an answer to the i/RFI	The supervisor instructed the subcontractor to rectify the reinforcement and ensure it conformed to Australian Standards instead of that specified on the IFC drawings	The supervisor ensured the work progressed and assured the subcontractor they would not be financially impacted — accountability lay solely with the alliance.
Micro	The supervisor identified there are labour shortages due to COVID-19	The supervisor determined that safety performance could be jeopardised, as the subcontractor had to work to a fixed timeline with limited resources. Additional resources were added to help supervise and rectify works.	The supervisor reviewed the labour force situation, checked for fatigue and well-being, and prepared for the next day's activities.
Macro	Lessons learned provided for future projects were communicated, shared, and discussed within the project and the alliance.	The supervisor openly communicated with subcontractors to be impacted and worked with them to minimise delays and productivity impacts.	How the rework was planned and managed, and its impacts were examined. Discussions with the subcontractor about how things could have been better handled were identified. Amendments to reinforcement specifications were made to ensure Australian Standards were met.

complacency creep was prominent. Reinforcing the need to adhere to quality control processes will go some way to addressing this problem. However, besides alliancing and providing key subcontractors with an opportunity to develop their capabilities, there remains no incentive to improve their performance through positive reinforcement (e.g., financial reward by extending the PAA). In some cases, key subcontractors have been integrated into an alliance entity to provide their input into the design and procurement process (Department of Infrastructure and Transport, 2010). After all, subcontractors operate at the sharp end of the production process.

5.1. Theoretical implications

The context and situations within which error-making rework materialises in ETO production systems have not been previously examined, especially under varying procurement arrangements where the allocation and management of risk can adversely influence the behaviours and (in)actions of organisations and people. Recognising the need to understand the context within which rework manifests in varying forms of ETO production systems and the important limitations of an 'error-as-event' archetype (Frese and Keith, 2015), our resilient error-as-process archetype (Lei and Naveh, 2023) provides a realistic representation of practice for infrastructure projects delivered using a relational procurement approach.

Our archetype, grounded in error management theory, provides a new representation from which we can understand the context (i.e., triggers, activities, and interactions), resulting in rework. It also identifies practices that can be utilised to detect, adapt, respond, and manage errors, enabling understanding of how, when, and why rework emerges due to its built-in feedback mechanisms. Such feedback is pivotal for learning and enacting change. In this sense, the resilient 'error-as-process' lens can provide us with a degree of explanatory power to rationalise the management of errors in the ETO production system of construction.

5.2. Practical implications

Besides providing a new theoretical framing for examining rework in relational ETO production systems, several takeaways for practice can be gleaned from this research. Firstly, the design of the ETO procurement arrangement to deliver major infrastructure assets influences how risks are managed. When risks are shared, the latent conditions directly impacting a project can be better managed. They will still exist, but the expectation that a single organisation shoulders the risk of latent conditions in an environment prone to VUCA will undoubtedly jeopardise a project's performance. The inequitable allocation of risks provides a breeding ground for opportunistic behaviours to manifest and the establishment of adversarial relations (Love et al., 2018b). A contractual joint venture agreement (CVA), such as PAA, can remedy these behaviours and engender collaboration, which is needed to manage errors effectively. Thus, any established CVA should be extended to key subcontractors beyond the two independent entities, which typically form the basis of the agreement. Providing subcontractors with incentives in their contracts has been shown to help them better manage their risks and reduce their rework costs (Chen et al., 2023).

Secondly, to address complacency creep, which was repeatedly identified as a contributor to error-making in several dissimilar situations of the ETO production system, we suggest regular compliance training is undertaken to keep project teams and subcontractors informed and educated on regulations, procedures, and quality controls. Training can also help people understand the potential consequences (e.g., the impact on cost, safety, and possible legal implications) of failing to follow specified guidelines and provide updated information on changes to regulations and best practices.

Finally, the practices of error management, such as analysing and communicating about errors and rework, can be readily employed by construction organisations with minimal, if any, impact on their operations. A case in point is shown in Table 2, where the supervisor and a concrete subcontractor worked together to adapt and respond to an error event. However, for such practices to be effectively applied, organisations need to accept that 'errors happen' rather than possess a mindset where 'errors can and need to be prevented'. Unfortunately, this mindset, by and large, pervades practice in ETO production systems. Accordingly, construction organisations have been unable to make the inroads needed to 'learn through errors' and effectively contain and reduce errors and mitigate rework.

6. Conclusions

Despite the widespread attention afforded to understanding the dynamics of rework in ETO production systems, particularly in construction, limited progress has been made in reducing its consequential impacts. Notably, archetypes that provide managers with guidance to mitigate rework effects in ETO production systems exist, and while informative, they are only conceptual and do not consider error-making. However, if significant strides are to be made toward mitigating rework in an ETO production system, an archetype that considers how organisations deal with and manage errors is required. This paper fulfils this need by using an 'error-as-process' lens; we develop an archetype based on error management theory and the actualities of practice to answer the following research questions: (1) How and why do errors and rework occur? and (2) considering emergent best practices, how should a project system adapt and respond to errors and manage rework?

To address these questions, we utilised an interpretative case study approach and drew on an AU$19.8 billion transport infrastructure project's – relational ETO production system – experiences with managing errors and rework. We examined four rework events through our resilient 'error-as-process' lens and explained their occurrence. Each rework event that materialised arose from dissimilar contexts. Still, recurring latent conditions (e.g., production pressure, limited resources, and procedural drift) and contributory factors (e.g., complacency creep and miscommunication) were identifiable. We also reveal that the alliance was able to adapt and respond to errors and its rework through building resilience into its production system's ecosystem by enhancing its team and subcontractors' adaptive capacity, which provided them with the ability to cope with process variability and thus understand 'why things go wrong' and 'why things go right'.

We discuss our findings' theoretical and practical implications, pointing out that contractual joint venture agreements play an integral role in establishing collaboration, implementing organisational error management practices, and incentivising performance. To this end, the contributions of our paper are twofold as it provides: (1) a new archetype and theoretical framing to examine rework in relational ETO production systems in VUCA environments; and (2) organisations with a *vade mecum* to help them effectively handle errors and rework in relational ETO production systems.

Going forward, we suggest our resilient 'error-as-process' archetype should be examined in other forms of the ETO production system (e.g., shipbuilding and oil and gas) and throughout its supply chain. While our process lens was restricted and indicative of a relational ETO production system of construction, future research is required to validate our 'error-as-process archetype' so that 'best practices' can be identified and drawn upon to contain and reduce errors and mitigate rework. Moreover, our resilient error-as-process archetype should be tested in other ETO production systems, such as shipbuilding and oil and gas, where relational contracting prevails to determine if it is generalisable. Indeed, there are many facets to the notion of resilience, reflecting the capabilities of ETO production systems to absorb and recover from disturbances such as errors and rework. Regardless, our study has only scratched the surface of how relational ETO production systems can incorporate resilience throughout their supply chains. Therefore, research is required to understand how resilience can be embedded into all ETO production systems to produce successful outcomes, regardless of the procurement strategy adopted.

CRediT authorship contribution statement

Peter E.D. Love: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Jane Matthews:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Lavagnon A. Ika:** Writing – review & editing, Writing – original draft.

Data availability

The data that has been used is confidential.

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Appendix. Interview Protocol

The operational definition of rework is "the total direct cost of redoing work in the field regardless of the initiating cause and explicitly excluding change orders and errors caused during off-site manufacture". Constructs from the error-as-process archetype identified in Fig. 2 are mapped to each question and identified in *italics*.

(1) What is your role in the project?
(2) Are the risks of rework considered in this project? What is done to manage the risk of rework? What are the main forms of rework that you come across?) *(Latent conditions, prevention, detection, and error management)*
(3) Have you been directly involved with a rework event or witnessed one in this project?
(4) If you were involved, can you describe the conditions and events that resulted in the rework event occurring and the consequences (e.g., costs, environmental, delays, stoppages, additional transportation)? *(Latent conditions and contributory factors)* Questions to consider:
   - What actions were undertaken to resolve the issue? *(Error management)*
   - How long did it take to rectify the problem once it was identified? *(Detection)*
   - Could it have been rectified quicker? *(Detection)*
   - What was the response of the supervisor/site management team? *(Error management)*
   - Were there any safety issues during the rectification of works? Was the rework formally documented (and why)? *(Prevention)*
   - What could have been done to prevent the problem from arising? How common are events of this nature? *(Prevention)*
   - Do you feel that you will be penalised/blamed for reporting a problem? (Prevention)
   - How would you describe the culture of the project? (What importance is given to assuring quality). *(Error management/prevention)*
     - o How difficult or easy is it for people to talk about errors/rework?
     - o What types of errors/rework do people talk about?
     - o Does the project have a clear vision or mission and a conscious approach toward errors/rework?
- What continuous improvement initiatives are you aware of in the project, and in your opinion, have they been effective? If not, why? *(Prevention, detection, and error management)*

References

Abdul-Rahman, H., 1995. The cost of non-conformance during a highway project: a case study. Construct. Manag. Econ. 13 (1), 23–32. https://doi.org/10.1080/01446199500000004.

Alexander, J., Ackermann, F., Love, P.E.D., 2019. Taking a holistic exploration of the project life cycle in public-private partnerships. Proj. Manag. J. 50 (6), 673–685. https://doi.org/10.1177/875697281984.

Alfnes, E., Gosling, J., Naim, M., Dreyer, H.C., 2023. Rearticulating supply chain design and operation principles to mitigate uncertainty in the Norwegian engineer-to-order shipbuilding sector. Int. J. Prod. Econ. 262, 108903 https://doi.org/10.1016/j.ijpe.2023.108903.

Altmann, E., Trafton, J.G., Hambrick, D.Z., 2014. Momentary interruptions can derail the train of thought. J. Exp. Psychol. Gen. 143 (1), 215–226. https://doi.org/10.1037/a0030986.

Armitage, G., 2009. Human error theory: relevance to nurse management. J. Nurs. Manag. 17 (2), 193–202. https://doi.org/10.1111/j.1365-2834.2009.00970.x.

Barber, P., Sheath, D., Tomkins, C., Graves, A., 2000. Quality failures in civil engineering. Int. J. Qual. Reliab. Manag. 17 (4/5), 479–492. https://doi.org/10.1108/02656710010298544.

Batista, C., Bourlakis, P., Smart, P., Maull, R., 2018. In search of a circular supply chain archetype – a content-analysis-based literature review. Prod. Plann. Control 29 (6), 438–451. https://doi.org/10.1080/09537287.2017.1343502.

Bhalla, S., Alfnes, E., Hvolby, H.-H., 2023. Tools and practices for tactical delivery date setting in engineer-to-order environments: a systematic literature review. Int. J. Prod. Res. 61 (7), 2339–2371. https://doi.org/10.1080/00207543.2022.2057256.

Braglia, M., Dallasega, P., Marrazzini, L., 2022. Overall construction productivity: a new lean metric to identify construction losses and analyse their causes in engineer-to-order construction supply chains. Prod. Plann. Control 33 (9/10), 925–942. https://doi.org/10.1080/09537287.2020.1837931.

Braun, V., Clarke, V., 2022. Conceptual and design thinking for thematic analysis. Qualitative Psychology 9 (1), 3–26. https://doi.org/10.1037/qup0000196.

Berling, P., Sonntag, D.R., 2022. Inventory control in production-inventory systems with random yield and rework: the unit-tracking approach. Prod. Oper. Manag. 31 (6), 2628–2645. https://doi.org/10.1111/poms.13706.

Cannas, V.G., Gosling, J., 2021. A decade of engineering-to-order (2010-2020): progress and emerging themes. Int. J. Prod. Econ. 24, 108274.

Chen, Z., Zhu, W., Crama, P., 2023. Subcontracting and rework cost sharing in engineering-procurement-construction projects. Int. J. Prod. Econ. 262, 1008901 https://doi.org/10.1016/j.ijpe.2023.108901.

Cigolini, R., Gosling, J., Iyer, A., Senicheva, O., 2022. Supply chain management in construction and engineer-to-order industries. Prod. Plann. Control 33 (9–10), 803–810. https://doi.org/10.1080/09537287.2020.1837981.

Dekker, S., 2017. A Field Guide to Understanding' Human Error', third ed. CRC Press, London, UK. https://doi.org/10.1201/9781317031833.

Dekker, S., 2013. The problems of zero vision in work safety. http://sidneydekker.com/wp-content/uploads/2013/01/MalaysiaLR.pdf, 18th August 2023.

Department of Infrastructure and Transport. 2010. Infrastructure planning and delivery: Best practice case studies. Commonwealth of Australia, Volume 2, Available at: https://www.infrastructure.gov.au/sites/default/files/migrated/infrastructure/publications/files/Best_Practice_Guide.pdf. (Accessed 4 October 2023).

Dimitrova, N., van Hooft, E.A.J., van Dyck, C., Groenewegen, P., 2017. Behind the wheel: what drives the effects of error handling. J. Soc. Psychol. 157 (6), 658–672. https://doi.org/10.1080/00224545.2016.1270891.

Dyer, J.H., Singh, H., 1998. The relational view: cooperative strategy and sources of inter-organisational competitive advantage. Acad. Manag. Rev. 23 (4), 660–679. https://doi.org/10.2307/259056.

Efatmaneshnik, M., Shoval, S., 2023. Stochastic modelling of process scheduling for reduced rework cost and scrap. Int. J. Prod. Res. 61 (1), 219–237. https://doi.org/10.1080/00207543.2021.2005267.

Escrig Tena, A.B., Bou Llusar, J.C., Roca Puig, V., 2001. Measuring the relationship between total quality management and sustainable competitive advantage: a resource-based view. Total Quality Management Journal 12 (7/8), 932–938. https://doi.org/10.1080/09544120100000018.

Flapper, S.D.P., Teunter, R.H., 2004. Logistics planning of rework with deteriorating work-in-progress. Int. J. Prod. Econ. 88 (1), 51–59. https://doi.org/10.1016/S0925-5273(03)00130-0.

Flapper, S.D.P., Fransoo, J.C., Broekmeulen, R.A.C.M., Inderfurth, K., 2002. Planning and control of rework in the process industries: a review. Prod. Plann. Control 13 (1), 26–34. https://doi.org/10.1080/09537280110061548.

Feigenbaum, A.V., 1991. Total Quality Control, third ed. McGraw-Hill, New York, NY.

Ford, G., Gosling, J., Naim, M., 2023. On quality and complexity: non-conformance failures, management perspectives and learning outcomes on a highways megaproject. Int. J. Qual. Reliab. Manag. https://doi.org/10.1108/IJQRM-11-2022-0313.

Frese, M., 1991. Error management or prevention. Two strategies to deal with errors in software design. In: Bullinger, H.-J. (Ed.), Human Aspects in Computing: Design and Use of Interactive Systems and Work with Terminals. Elsevier, Amsterdam.

Frese, M., Keith, N., 2015. Action errors, error management and learning in organisations. Annu. Rev. Psychol. 66, 661–687. https://doi.org/10.1146/annurev-psych-010814-015205.

Gardner, J.W., 2020. Managing production yields and rework through feedback on speed, quality and quantity. Prod. Oper. Manag. 29 (9), 2182–2209. https://doi.org/10.1111/poms.13221.

Gates, D., 2021. Boeing returns to red ink, projects $1 billion lost from 787 quality issues". Settle Times, 27th October Available: https://www.seattletimes.com/business/boeing-aerospace/boeing-projects-1-billion-lost-from-787-quality-issues/?amp=1, 26th May 2023.

Gosling, J., Naim, M.M., 2009. Engineer-to-order supply chain management: a literature review and research agenda. Int. J. Prod. Econ. 122, 741–754. https://doi.org/10.1016/j.ijpe.2009.07.002.

Gosling, J., Towill, D.R., Naim, M.M., Dainty, A.R.J., 2015. Principles for the design and operation of engineer-to-order supply chains in the construction sector. Prod. Plann. Control 26 (3), 203–218. https://doi.org/10.1080/09537287.2014.880816.

Gosling, J., Hewlett, B., Naim, M., 2020. Procurement and contractual choices for engineer-to-order supply chains. IEEE Eng. Manag. Rev. 49 (1), 174–180. https://doi.org/10.1109/EMR.2020.3028027.

Hall, M., Tomkins, C., 2001. A cost of quality analysis of a building project: towards a complete methodology for design and build. Construct. Manag. Econ. 19 (7), 727–740. https://doi.org/10.1080/01446190110066146.

Hayek, P.A., Salameh, M.K., 2001. "Production lot sizing with the reworking of imperfect quality items produced". Prod. Plann. Control 12 (6), 584–590. https://doi.org/10.1080/095372801750397707.

Hietajärvi, A.-M., Aaltonen, K., 2018. The formation of a collaborative project identity in an infrastructure alliance project. Construct. Manag. Econ. 36 (1), 1–21. https://doi.org/10.1080/01446193.2017.1315149.

Hughes, E.C., 1951. Mistakes at work. Can. J. Econ. Polit. Sci. 17 (3), 320–327. https://doi.org/10.2307/137687.

Hunsaker, P.L., Alessandra, A.J., 1991. The Art of Managing People. Simon & Schuster, NY.

Ivancic, K., Hesketh, B., 2000. Learning from errors in a driving simulation: effects on driving skill and self-confidence. Ergonomics 43 (12), 1966–1984. https://doi.org/10.1080/00140130050201427.

Junge, G., Alfnes, E., Nujen, B., Emblemsvag, J., Kjersem, J., 2023. Understanding and eliminating waste in Engineer-To-Order (ETO) projects: a multiple case study. Prod. Plann. Control 34 (3), 225–241. https://doi.org/10.1080/09537287.2021.1903279.

Kaynak, K., 2003. The relationship between total quality management practices and their effects on firm performance. J. Oper. Manag. 23 (9), 795–816. https://doi.org/10.1016/S0272-6963(03)00004-4.

LaBerge, D., Samuels, S.J., 1974. Towards a theory of automatic information processing in reading. Cognit. Psychol. 6 (2), 293–323. https://doi.org/10.1016/0010-0285(74)90015-2.

Lahdenperä, P., 2012. Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery. Construct. Manag. Econ. 30 (1), 57–79. https://doi.org/10.1080/01446193.2011.648947.

Lei, Z., Naveh, E., 2016. Errors in organisations: an integrative review via the level of analysis, temporal dynamism, and priority lenses. J. Manag. 42 (5), 1315. https://doi.org/10.1177/0149206316633745, 143.

Lei, Z., Naveh, E., 2023. Unpacking errors in organisations as processes: integrating organisational research and operations management literature. Acad. Manag. Ann. 17 (2), 798–844. https://doi.org/10.5465/annals.2021.0066.

Leonard-Barton, D., 1992. The factory as a learning laboratory. Sloan Manag. Rev. 34 (1), 23–38.

Li, L., Shan, S., Dai, J., Che, W., Shou, Y., 2022. The impact of green supply chain management on green innovation: a meta-analysis from the inter-organisational learning perspective. Int. J. Prod. Econ. 250, 108622 https://doi.org/10.1016/j.ijpe.2022.108622.

Linderman, K., Schroeder, R.G., Zaheer, S., Liedtke, C., Choo, A.S., 2004. Integrating quality management practices with knowledge creation processes. J. Oper. Manag. 22 (6), 589–607. https://doi.org/10.1016/j.jom.2004.07.001.

Love, P.E.D., 2020. Creating a mindfulness to learn from errors: enablers of rework containment and reduction in construction. Developments in the Built Environment 1 (1), 100001. https://doi.org/10.1016/j.dibe.2019.100001.

Love, P.E.D., Li, H., 2000. Overcoming the problems associated with quality certification. Construct. Manag. Econ. 18 (2), 139–149. https://doi.org/10.1080/014461900370771.

Love, P.E.D., Smith, J., 2016. Toward error management in construction: moving beyond a zero vision. ASCE Journal of Construction Engineering & Management 142 (11) (ASCE)CO.1943-7862.0002270.

Love, P.E.D., Matthews, J., 2020. Quality, requisite imagination and resilience: managing risk and uncertainty in construction. Reliab. Eng. Syst. Saf. 204, 107172 https://doi.org/10.1016/j.ress.2020.107172.

Love, P.E.D., Matthews, J., 2022. The social organisation of errors and the manifestation of rework: learning from narratives of practice. Prod. Plann. Control. https://doi.org/10.1080/09537287.2022.2117664.

Love, P.E.D., Matthews, J., 2024. Error mastery in alliance transport megaprojects. IEEE Trans. Eng. Manag. 71, 1819–1836. https://doi.org/10.1109/TEM.2022.3151494.

Love, P.E.D., Smith, J., Ackermann, F., Irani, Z., 2018a. The praxis of stupidity: an explanation to understand the barriers mitigating rework in construction. Prod. Plann. Control 29 (13), 1112–1125. https://doi.org/10.1080/09537287.2018.1518551.

Love, P.E.D., Smith, J., Ackermann, F., Irani, Z., Teo, P., 2018b. The costs of rework: insights from construction and opportunities for learning. Prod. Plann. Control 29 (13), 1082–1095. https://doi.org/10.1080/09537287.2018.1513177.

Love, P.E.D., Smith, J., Ackermann, F., Irani, Z., Fang, W., Luo, H., Ding, L., 2019a. Houston, we have a problem! Understanding the tensions between quality and safety in construction. Prod. Plann. Control 30 (16), 1354–1365. https://doi.org/10.1080/09537287.2019.1617908.

Love, P.E.D., Smith, J., Ackermann, F., Irani, Z., 2019b. Making sense of rework and its unintended consequence in projects: the emergence of uncomfortable knowledge in practice. Int. J. Proj. Manag. 37 (3), 501–516. https://doi.org/10.1016/j.ijproman.2019.02.004.

Love, P.E.D., Matthews, J., Sing, M.C.P., Porter, S.R.M., Fang, W., 2022a. State of science: why does rework occur in construction? What are its consequences? And what can be done to mitigate its occurrence? Engineering 18, 246–258. https://doi.org/10.1016/j.eng.2022.05.010.

Love, P.E.D., Pinto, J.K., Ika, L.A., 2022b. Hundreds of years with pain, with minimal gain: capital project cost overruns, the past, present and optimistic future. IEEE Eng. Manag. Rev. 50 (4), 56–70. https://doi.org/10.1109/EMR.2022.3219362.

Love, P.E.D., Matthews, J., Ika, L.A., Fang, W., 2022c. Error culture and its impact on rework: an exploration of norms and practices in a transport megaproject. Developments in the Built Environment 10, 100067. https://doi.org/10.1016/j.dibe.2022.100067.

Love, P.E.D., Matthews, J., Ika, L.A., Teo, P., Fang, W., Morrison, J., 2023. From Quality-I to Quality-II: cultivating an error culture to support lean thinking and rework mitigation in infrastructure projects. Prod. Plann. Control 34 (9), 812–829. https://doi.org/10.1080/09537287.2021.1964882.

Love, P.E.D., Matthews, J., Ika, L.A., Fang, W., 2024. Rumsfeld's heuristic: a metaphor for understanding the knowns and unknowns of rework in construction. IEEE Eng. Manag. Rev. 52 (1), 43–59. https://doi.org/10.1109/EMR.2023.3322626.

Matthews, J., Love, P.E.D., Ika, L.A., Fang, W., 2022a. Error aversion or error management? Error culture at the sharp end of production. Developments in the Built Environment 10, 100074. https://doi.org/10.1016/j.dibe.2022.100074.

Matthews, J., Love, P.E.D., Porter, S.R., Fang, W., 2022b. Smart data and business analytics: a theoretical framework for managing rework risks in megaprojects. Int. J. Inf. Manag. 102495 https://doi.org/10.1016/j.ijinfomgt.2022.102495.

Mellat-Parast, M., Digman, L.A., 2008. "Learning: the interface of quality management and strategic alliances. Int. J. Prod. Econ. 114, 820–829. https://doi.org/10.1016/j.ijpe.2008.04.003.

Reason, J., 1990. Human Error. Cambridge University, Press. https://doi.org/10.1017/cbo978113062367.

Reason, J., 2000. Human error: models and management. BMJ 320 (7237), 768–770. https://doi.org/10.1136/bmj.320.7237.768.

Robinson-Fayek, A., Dissanayake, M., Campero, O., 2004. Developing a standard methodology for measuring and classifying construction fieldwork. Can. J. Civ. Eng. 31 (6), 1077–1089. https://doi.org/10.1139/l04-068.

Sarker, B.R., Jamal, A., Mondal, S., 2008. Optimal batch sizing in a multi-stage production system with rework consideration. Eur. J. Oper. Res. 184 (3), 915–929. https://doi.org/10.1016/j.ejor.2008.04.015.

Scheublin, F.J.M., 2010. "Project alliance contract in The Netherlands. Build. Res. Inf. 1 (6), 451–455. https://doi.org/10.1080/09613210110083627.

Senge, P., 1990. The Fifth Discipline: the Art and Practice of the Learning Organisation. Random House, London, UK.

Sitkin, S.B., Sutcliffe, K.M., Schroeder, R.G., 1994. Distinguishing control from learning in total quality management: a contingency perspective. Acad. Manag. Rev. 19 (3), 537–564. https://doi.org/10.2307/258938.

Sofiana, A., Rosyidi, C.N., Pujiyanto, E., 2019. Product quality improvement model considering quality investment in rework policies and supply chain profit sharing. Journal of Industrial Engineering International 15, 637–649. https://doi.org/10.1007/s40092-019-0309-7.

Sousa, R., Voss, C.A., 2002. Quality management re-visited: a reflective review and agenda for research. J. Oper. Manag. 20 (1), 91–109. https://doi.org/10.1016/S0272-6963(01)00088-2.

Stake, R.E., 1995. The Art of Case Study Research. Sage Publications Ltd, London.

Stewart, D.M., Grout, J., 2001. The human side of mistake proofing. Prod. Oper. Manag. 10 (4), 440–459. https://doi.org/10.1111/j.1937-5956.2001.tb00086.x.

Teunter, R.H., Bayindir, Z.P., Van Den Heuvel, W., 2006. Dynamic lot sizing with product returns and remanufacturing. Int. J. Prod. Res. 44 (20), 4377–4400. https://doi.org/10.1080/00207540600693564.

Tzortzopoulos, P., Kagioglou, M., Koskela, L., 2020. Lean Construction: Core Concepts and New Frontiers. Routledge, London, UK.

Van Dyck, C., Frese, M., Baer, M., Sonnetag, S., 2005. Organisational error management culture and its impact on performance: a two-study replication. J. Appl. Psychol. 90 (6), 1228–1240. https://doi.org/10.1037/0021-9010.90.6.1228.

Walker, D.H.T., Rowlinson, S., 2020. Handbook of Integrated Project Delivery. Routledge, Abingdon, UK, 101201/9781315185774.

Walker, D.H.T., Love, P.E.D., Matthews, J., 2023. Generating value in program alliances: the value of dialogue in large-scale infrastructure projects. Prod. Plann. Control. https://doi.org/10.1080/09537287.2023.2202631.

Weinstein, N.D., 1984. Why it won't happen to me: perceptions of risk factors and susceptibility. Health Psychol. 3 (5), 431–457. https://doi.org/10.1037/0278-6133.3.5.431.

Westrum, R., 1991. Technologies and Society: the Shaping of People and Things. Wadsworth, Belmont, CA.

Wildavsky, A.B., 1988. Searching for Safety: Social Theory and Social Policy. Routledge, New York. https://doi.org/10.4324/9781351316248.

Williams, T.A., Gruber, D.A., Sutcliffe & Shepard, D.A., 2017. Organisational response to adversity: fusing crisis management and resilience research streams. Acad. Manag. Ann. 11 (2), 733–769. https://doi.org/10.5465/annals.2015.0134.

XYZ, 2022. Rethinking Rework: Exploring the Causes of and Solutions to Construction's Most Expensive Problem. White Paper. Available at: https://www.xyzreality.com/resources/rethinkingrework, 31st March 2023.

Young, G.J., Charns, M.P., Shortell, S.M., 2001. "Top manager and network effect on the adoption of innovative management practices: a study of TQM in a public hospital system. Strat. Manag. J. 22 (10), 935–951, 10.1002/smj.194.

Zeetsloot, G.I.J.M., Aaltonen, J.M., Wybo, J.-L., Saari, J., Kines, P., Beek, R.O.D., 2013. The case for research into zero vision accidents. Saf. Sci. 58, 41–48. https://doi.org/10.1016/j.ssci.2013.01.026.

Zhou, Y., Wang, X., Naim, M.N., Gosling, J., 2022. A system dynamics archetype to mitigate rework effects in engineer-to-order supply chains. Int. J. Prod. Econ. 108620 https://doi.org/10.1016/j.ijpe.2022.108620.

Zhou, Y., Wang, X., Gosling, J., Naim, M.M., 2023. The system dynamics of engineer-to-order construction projects: past, present, and future. ASCE Journal of Construction Engineering and Management 149 (5), 03123004.