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State of Science: Why Does Rework Occur in Construction? What Are Its Consequences? And What Can be Done to Mitigate Its Occurrence?

Peter E.D. Love [a], Jane Matthews [b], Michael C.P. Sing [c], Stuart R. Porter [a], Weili Fang [a,d,*]

[a] School of Civil and Mechanical Engineering, Curtin University, Perth, WA 6845, Australia
[b] School of Architecture and Built Environment, Deakin University Geelong Waterfront Campus, Geelong, VIC 3220, Australia
[c] School of Architecture and Built Environment, The University of Newcastle, Callaghan, NSW 2308, Australia
[d] Department of Civil and Building Systems, Technische Universität Berlin, Berlin 13156, Germany

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A B S T R A C T

There has been a wealth of research that has examined the nature of rework in construction. Progress toward addressing the rework problem has been limited—it still plagues practice, adversely impacting a project's performance. Almost all rework studies have focused on determining its proximal or root causes and therefore have overlooked the conditions that result from its manifestation. In filling this void, this paper draws upon our previous empirical studies, amongst others, to provide a much-needed theoretical framing to understand better why rework occurs, what its consequences are, and how it can be mitigated during construction. The theoretical framing we derive from our review provides construction organizations and their projects with a realization that the journey to mitigating rework begins with creating an error-mastery culture comprising authentic leadership, psychological safety, an error-management orientation, and resilience. We suggest that, once an error-mastery culture is established within construction organizations and their projects, they will be better positioned to realize the benefits of the techniques, tools, and technologies espoused to address rework, such as the Last Planner® and building information modeling. We also provide directions for future research and identify implications for practice so that strides toward rework mitigation in construction can be made.

1. Introduction

The Sampoong Department Store (Seoul, Republic of Korea) collapsed on 29 June 1995, killing 502 and injuring 937 people. Lee Joon, the store owner, modified the building during its construction by adding a fifth floor when it had only been designed to support four. The store collapsed due to a structural failure—more than 1500 people were in the luxury department store when it collapsed. The collapse was primarily blamed on shoddy (poor-quality) construction and corruption. Lee Joon was charged and found guilty of criminal negligence and sentenced to ten and a half years in prison. His son was arrested, found guilty, and received a seven-year prison sentence. The defendants' relatives wept softly as the verdicts were read. Throughout the trial, prosecutors painted a chilling picture of a store owner more concerned with maximizing profits than customer safety and of city officials willing to take bribes in exchange for allowing illegal design and construction. "Therefore, they are responsible for the collapse" said the head of a three-judge panel before he read the sentences [1].

The Sampoong Department Store disaster should never have happened, but ill-considered decisions, turning a blind eye to poor quality and corruption provided the conditions for its collapse. Despite the sheer number of buildings, bridges, and dams, and the like collapsing since the Fidenae amphitheatre in 27AD (Fidenae, Italy), engineering failures are an ever-present reality causing significant economic and societal harm.

Examples of well-known calamities that similarly should never have happened include the Westgate Bridge in 1970 (Melbourne, Australia), the Rana Plaza in 2013 (Dhaka, Bangladesh), and the Siji Kaiyuan Hotel in 2021 (Suzhou, China). Harsh lessons can be learned from such events, as engineers can uncover, document, and change their designs to enable improvements and technological innovations to emerge and be adopted [2,3]. Reinforcing this point, Petroski [3] cogently explains that failures "always teach us more than success about the design of things. And thus, the fail-

* Corresponding author.
E-mail address: weili.fang@protonmail.com (W. Fang).

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ures often lead to redesigns—to new, improved things" (p. 63). Repeatedly, engineering errors, poor-quality construction, miscreant behavior, and violations of standards and regulations are typical contributors to disasters [4]. Regardless of the countless number of studies addressing engineering failures in construction, we still struggle to mitigate them, as we tend to overlook the conditions (i.e., so-called 'pathogenic' influences) that result in their occurrence [4–6].

Setting aside corruption[†] [7] (including bribery, extortion, fraud, and cartels), as it is secretive and difficult to detect [8,9], we have been unable to make headway toward questioning the engineering design decisions and mitigating people's (in)actions during construction that contribute to the occurrence of engineering failures. When errors and violations (also referred to as active failures) are identified, rework[‡] [10–13] may be required, negatively impacting an organization's profitability and reputation, as well as a project's productivity, safety, and environmental performance [10]. Thus, if we can mitigate errors and violations during the construction of an infrastructure asset, rework can be reduced and inroads can be made to prevent engineering failures [6].

Calls for greater investment in infrastructure, for example, have been made in the United States as a consequence of the Pittsburgh Bridge collapse in late January 2022, which is perceived to have occurred due to deferred maintenance [14]. In response, clarion calls have been made to throw money at the problem, although this is not the immediate solution. Indeed, there is a need for funding to upgrade and maintain bridges in the United States, but such assets need to be designed and constructed with 'error resilience' in mind. However, this has not been the case for infrastructure assets worldwide, which we bring to the fore in this paper.

The need to perform rework is a pervasive problem in construction [6]. Accordingly, an extensive body of work has been undertaken to determine the costs and causes of rework and to propose strategies to prevent its occurrence [11–13,15–24]. Such studies have focused on determining proximal (i.e., singular) rework causes, using prefixes such as 'poor,' 'lack of,' 'inappropriate,' and 'inadequate,' and thus have neglected the interdependency of events leading to its occurrence. Moreover, there has been a tendency to view errors (e.g., lack of skills or knowledge) as causes rather than consequences of systemic factors [5].

The perpetual reporting of singular variables (e.g., poor communication, lack of coordination, and improper material handling) that have an absence of a context has led to the creation of artificial narratives of rework causation that undermine the complexity of the problem, which has been described as being 'wicked' [25]. In sum, rework studies that have focused on identifying proximal causes provide an over-simplification of causality.

In addition, some studies have focused on identifying single (or a few) root causes [10–16,18,19,22–24,26]. This approach promotes a reductionist view of causation, which we consider to be flawed, as multiple interacting contributions are often at play [25]. Consequently, this view has hindered scholars' ability to understand the context and conditions that lead to the manifestation of rework and their means to reduce its incidence in construction [27–30]. That is, the 'reductionist' perspective, which has traditionally been adopted to determine rework causation, relies on the use of 'one-size-fits-all' prevention strategies [15,17,20,21,23,24]. However, various error types evoke different responses, suggesting that strategies to address rework need to be tailor-made to the context in which they occur [6,7,27–29].

While we know that rework in construction can adversely impact project performance, we still have limited knowledge about its initial conditions, its consequences, and how best to mitigate its occurrence, despite the considerable amount of research undertaken. Hence, the motivation of this paper is to shift the focus away from determining proximal and root causes, as seen in Asadi et al. [23], which reinforces a repeated discourse resembling 'new wine in old wineskins.' Thus, we require a new line of thinking in which the context and initial conditions matter [25,26].

Without an understanding of the context, it is not possible to develop solutions to mitigate rework [30]. Thus, we draw upon our previous empirical research [27–30] to provide a context to the rework problem and, in doing so, move the prevailing discourse forward from a position where people are viewed as being the cause (e.g., loss of situation awareness, procedural violation, and managerial deficiencies) to one where it is seen as a "symptom of trouble deeper inside the [organizational and project] system" [31, p. xii].

Our paper commences by introducing a nascent theoretical context to understand the etiology of rework that materializes during construction (Section 2). We then frame our paper around three fundamental questions to support the need for a new theoretical framing of rework. We first question why rework occurs, drawing on the error literature and our empirical research (Section 3). Then, we ask what the consequences of rework are (Section 4) and how it can be mitigated, drawing from best practices that we have observed in real-life projects (Section 5). Next, we identify the research (Section 6) and practical implications of our review (Section 7), before concluding the paper (Section 8). The contribution of our review to the contemporary error and rework literature is twofold: ① We present a theoretical context for rework causation and the role errors play in its manifestation; and ② build on the error-mastery culture theoretic proposed by Love and Matthews [29] by demonstrating how resilience (i.e., foresight, coping, and recovery) to errors can be incorporated into everyday practice in construction.

2. Theoretical context

The type of error culture within an organization and a project sets the tone for how people respond, share information, and deal with errors and their consequences [27–29]. An error-prevention culture dominates practice in construction. Table 1 presents the characteristics of such a culture [6,25,27,32–35].

Unwittingly, construction organizations have found such an error culture to be an Achilles' heel: It has hampered their ability to learn and mitigate rework, as errors are viewed negatively and are often covered up [25,27–30,36]. Having an error-prevention culture in place often results in rework becoming 'uncomfortable knowledge' (i.e., denied, dismissed, diverted, or displaced) or being explained away as a one-off event [34]. Nonetheless, errors enable organizations to learn and innovate, and thus should not be viewed in a negative light [2,32,37,38]. Only a limited number of studies have examined how errors and violations result in the need for rework in the construction and engineering management literature [27–30,36,39,40]. Thus, we will briefly explain the nature of errors and violations, as they are a source of rework. We present a rework nomenclature in Fig. 1 [41] and identify real-life examples of errors observed in our studies that have resulted in the issue of non-conformances.

To reiterate, our definition of rework does not consider change orders, as these form part of a construction organization's planned work when issued by a client [10]. More specifically, rework is an

[†] Corruption refers to "the abuse of public office for private gain" [7, p. 552].

[‡] Defined as "the total direct cost of re-doing work in the field regardless of the initiating cause and explicitly excluding change orders and errors caused during offsite manufacture" [10, p. 1078]. Various terms such as qualify deviations [11,12] and quality failures [13] have been used to describe the need for rework. These terms explicitly focus on quality issues, but some studies also include design and constructions [11,12] whereas others do not [13].

Table 1
Processes and outcomes of error prevention (negative view of errors).

Before an error	After an error	Interpersonal processes	Outcome
• People work hard to prevent errors and worry about committing them • Low levels of confidence	• People become stressed when errors are made	• People hide errors and are therefore reluctant to report them • People are fearful of being blamed for the occurrence of errors	• Counting of errors and the number reduced • Learning is hindered • Marginal performance improvements

Adapted from Ref. [32, p. 666].

unplanned activity and is seldom identified as a risk; rather, it is often viewed as a zemblanity (i.e., an unpleasant yet unsurprising discovery) [25].

2.1. Action errors

We adopt Frese and Keith's [32] notion of goal-directed actions to frame our definition of an error. Thus, action errors are defined as "unintended deviations from plans, goals, or adequate feedback processing, as well as an incorrect action that results from a lack of knowledge" [37, p. 1229]. When examining action errors and their consequences, the context within which they occur matters, as the environment within which people work influences their occurrence [38].

Making errors *per se* is not a problem. More often than not, in construction, errors are minor, as they are an unintended consequence of work activity [2, p. 256; 33]. Moreover, people "as part of their daily work activity commit errors routinely" [2, p. 256]. But, in some instances, errors can have serious consequences and thus need to be quickly identified before they contribute to a disaster. Most of the time, practitioners (e.g., design and project engineers, site supervisors, and subcontractors) discover their errors (and others) due to an array of procedures and systems (e.g., design audits and checks, Inspection Test Plans, and Last Planner®) that are put in place when designing and constructing an asset. However, there are occasions when errors remain unidentified due to constraints (e.g., production pressure) and the dynamic environment within which people work, which can lead to grave consequences [34].

Errors can occur due to impaired human cognition (e.g., slips and lapses of attention) and mistakes (i.e., rule- or knowledge-based) [41]. In the case of rule-based mistakes, a practitioner may misapply a rule that worked in a previous situation (e.g., using a different design) due to a changed condition. Relatedly, an imperfect rule may have remained uncorrected and formed part of a practitioner's problem-solving toolbox [41]. Similarly, knowledge-based mistakes emerge when practitioners encounter a novel situation outside the range of their learned problem-solving routines [41].

At an individual level, several issues influence our ability to make errors, including fatigue (e.g., workload, time of day, and sleep deprivation), stress (e.g., workload and time constraints), boredom (e.g., repetitive tasks), and inadequate training and/or limited experience. Team and organizational errors are also common contributors to rework. Accordingly, team errors can "occur as a result of the joint effect of antecedents across individual and team levels" [42, p. 1322]. Several scenarios can result in team errors occurring in projects; these include cases in which [29,43]:

- The entire project team does not detect an error and work continues;
- An individual commits an error that goes undetected, the team jointly decides on a course of action, unaware of the error;
- An individual error is detected, but the team decides not to correct it and continues the work.

Organizational errors are defined as the "actions of multiple organizational participants that deviate from organizationally specified rules and procedures that can potentially result in adverse organizational outcomes" (e.g., accidents, litigation, and reputational loss), especially in high-stakes settings such as construction [44, p. 154]. Hence, a rudimentary "feature of an organizational error is that multiple individuals deviate from the expected organizational practice" [44, p. 154]. In our previous studies, a typical example of an organizational error was the non-reporting of non-conformances during construction, as there is a perception that senior management views these as indicators

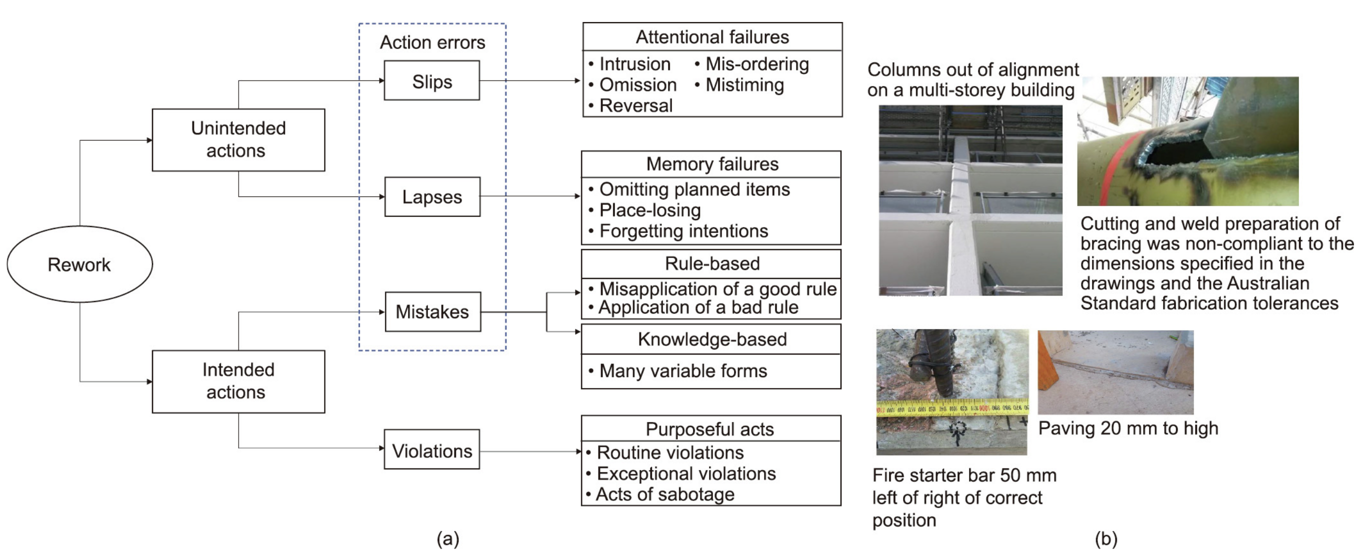

Fig 1. Rework nomenclature. (a) Rework: errors and violations; (b) examples of non-conformances requiring rework. (a) Adapted from Ref. [41, p. 207].

of a poorly managed project [29,30,33,34]. As a matter of fact, non-conformances provide learning and improvement opportunities for construction organizations. But, as we will discuss below, such opportunities are often forgone due to an organization's incumbent culture [28,29,36].

2.2. Violations: Rule breaking

In contrast to action errors, violations are the intentional breaking of rules and procedures that have been established to restrict self-interested behavior and protect "organizational members from the predations of others" [45, p. 36]. Moreover, violations may arise when there is a non-conformance to a standard, such as substituting a specified product/material for another and installing it without approval [34]. In this instance, we have observed that the motivation for such an action is to maximize profit (i.e., the substituted product/material is cheaper) or to adhere to a project's program so as not to cause a delay [34].

The breaking of formal rules is typically associated with deviant behavior, especially within the context of safety in construction. However, "there is a longstanding antithesis to this view that rules are in some simple sense order-producing and violation order-destroying. Part of this critique is that rules harm individual well being" [45, p.37]. In doing so, they can adversely impact job satisfaction, contributing to stress and absence, undermining organizational functioning, and impeding the facilitation of organizational change and learning [45].

With construction subjected to many rules, people need to consider their applicability to specific situations [46]. Rather than rule-breaking being viewed as a deviant behavior, it may be deemed to be "pro-social" and "a way of testing rules and the truces around them" [45, p. 36; 47]. Thus, in the case of a violation, the context and intentionality behind the person's (in)actions must be considered. People may intend to do the right thing but find themselves breaking a rule and *vice versa* [48]. It is notable that rules and procedures are often "written for the ideal situation," yet in construction, "work situations are rarely ideal" and are subject to constant change [48, p. 298].

If there was no intention to commit a violation, then the act can be categorized as an "unintended violation" [41, p. 195]. If there was a prior intention to cause damage to the system, then the violation is deemed to be "sabotage" [41, p. 35]. However, intentions are not always so black and white. Certain violations may "have some degree of intentionality, but do not involve the goal of system damage" [41, p. 195]. In such cases, violations can be categorized (Fig. 1) as either routine—that is, "habitual, forming a part of an individual's behavioral repertoire" [41, p. 195]—or exceptional—that is, "singular violations occurring in a particular set of circumstances" [41, p. 196].

Production pressure, the unavailability of skilled labor, pandemics (e.g., coronavirus disease 2019 (COVID-19)), incomplete design, and the like mean that rules may become problematic or may render it impossible for people to perform their work. In situations when rules are inappropriate, "alternative courses of action tend to be used to achieve the same ends" [48, p. 298]. As a result, this provides people who break the rules with the opportunity to concoct reasons for their actions. In doing so, people are viewed not as rational but as reasoning agents who create and convey their reasons through dialogue to others [49]. Thus, when examining deviant behavior, we need to consider the context within which it has occurred. As Pablo Picasso insightfully remarked, "learn the rules like a pro so that you can break them like an artist." Indeed, rules can be changed by challenging them, which can result in positive outcomes. Thus, we need to take heed of this point when we consider the issues associated with rework mitigation (Section 5).

3. Why does rework occur?

To recap, the construction and engineering management literature has ignored why errors and violations transpire. Therefore, understanding the nature of error-making and rule-breaking provides the impetus to address the rework problem, which equally applies to accidents [26,50]. In actual fact, a symbiotic relationship exists between quality and safety [51]. Thus, akin to the accident causation literature [41], where resident 'pathogens' (i.e., latent conditions) within a system engender error-making and violations, they can result in the manifestation of rework [52,53]. Such pathogens arise from the strategic decisions made by a construction organization's senior management and project clients [53].

Thus, pathogens tend to lay dormant, often for a considerable period, with people being unaware of their existence "within a system until an error [violation] comes to light" [53, p. 425]. As pathogens enter an incubation period, they become an integral part of everyday work practices [52,53]. When pathogens combine with active failures, then rework is often needed. Indeed, active failures are difficult—if not impossible—to foretell. In effect, errors and violations are seen in hindsight; until then, they are actions just like any other. However, pathogens can be identified and remedied before rework is needed [53].

In Table 2, Busby and Hughes [52] identify eight types of pathogens that emerged from a study of errors in large-scale engineering projects. Examples of pathogens identified by Busby and Hughes [52] and from the rework studies undertaken by Love et al. [35,53] are also presented in Table 2. Pathogens do not exist in isolation and can interact with one another. Therefore, being mindful of their interdependency improves the ability of organizations to redress resident pathogens holistically [36].

The practice pathogen has been identified as the most popular in projects [52,53]. For example, the practice of design re-use is often used to improve productivity and drive down costs in projects [52,53]. But this practice is "inherently vulnerable to unidentified differences between the context in which a re-used design first originates and the context in which it is re-used" [52, p. 431]. We have also seen design engineers failing to undertake detailed design reviews due to production pressure or minimizing costs [53]. The pathogen of circumstance is similarly ubiquitous in projects [53]. In this instance, two issues come to the fore [53–55]:

(1) The use of fast-tracking (i.e., overlapping design and construction activities) often results in commencing construction based on a tentative design.

(2) Traditional contracting (i.e., design–bid–construct), in which information asymmetry, adverse selection, opportunistic behavior, and moral hazards materialize, exists during the procurement process. The problems with traditional contracting are exacerbated when competitive tendering is enacted and the lowest bid is selected.

Besides the empirical studies of Busby and Hughes [52] and Love et al. [53], research examining the nature of pathogens and their associated incubation periods has not been forthcoming. Thus, further exploration is needed to garner an improved understanding and awareness of the implications of pathogens for decision-making and practice.

3.1. Functional stupidity management

Adding to the mix of pathogens and active failures, we have seen 'functional stupidity' at play in construction organizations, indirectly contributing to people making errors and committing violations [35]. Alvesson and Spicer [56] frame functional stupidity as an organizational issue and describe it as the incapacity and/or disinclination on the part of organizational members to exercise

Table 2
Description of pathogens and examples of errors.

Category	Pathogen resource [52, p. 429]	Busby and Hughes [52, p. 429]	Love et al. [53, p. 429] and Love et al. [35]
Practice	Peoples' deliberate practices	It was the practice for designs to be checked only for internal consistency, not consistency with external constraints and requirements	Failure to undertake design reviews and the distribution of tentative design documents to contractors
Task	The nature of the task being performed	Trace quantities of a contaminant had disproportionate consequences in a particular process design task	Engineers failed to detect and correct omissions in design documentation; furthermore, schedule pressure resulted in disproportionate time being allocated to tasks
Circumstance	Situation or environment the project was operating in	The firm procured services in a market where there was inadequate information about the quality of products	Low design fees meant that tasks were deliberately left out; schedule pressure resulted in some tasks not being recalled at the appropriate time
Convention	Conventions, standards, routines, and codes of practice	A person adhered to a company standard that had previously always been superseded by *ad hoc* agreements—which, as a result, had unknowingly become obsolescent	Re-using existing specifications and design solutions; also, failure to adhere to new company policies
Organization	Organizational structure or operation	The slow ramp-up of projects led to delay in early tasks on which many others were dependent for information and which therefore had to proceed on tentative assumptions	Blocking of communicative action due to an error-prevention culture and absence of psychological safety
System	An organizational system	Latency in a change control system meant that a significant amount of engineering	A trade-off between quality and safety; when a trade-off arises, having more of one element means less of the other; safety is given preference, as it is bound by legislation
Industry	Some structural properties of the industry	Public contracting regulations required that the firm consider vendors with whom the firm had no direct experience	Ever-present symbolic representation of a zero-vision and the notion that errors can be eliminated by striving for a zero-error culture
Tool	A characteristic of a technical tool	A design tool provided a layering facility that encouraged people to simplify their tasks but allowed them to forget possible inconsistencies with other parts of the design	Interoperability with computer-aided-design software applications (i.e., no checking for consistencies); simplification of tasks and neglect of other aspects of design

critical reflection about what they are doing (reflexivity), understand why they are doing it (justification), and determine what the consequences of their activities are beyond the immediate task at hand (substantive reasoning).

Akin Alvesson and Spicer [56], Love et al. [35] have observed that functional stupidity is linked to power and politics in construction organizations. In particular, Love et al. [35] observed that managers, working within their error-prevention culture, tried to shape the cognitive capacities and mindsets of their employees using symbolic manipulation to create "conformity and to limit critical thinking" [56, p. 1204].

3.2. Competing demands

Even though quality and safety are interdependent, construction organizations view them to be competing demands and have been unable to accommodate them equally, resulting in trade-offs occurring [8,27,33,35,50,51]. When a trade-off arises, there is a gradual exchange in which having more of one element means less of the other. In this instance, it has been observed that construction organizations typically provide more resourcing to safety, as it is bound by legislation, with the consequences of not adhering to regulations and the code of practice being potentially costly and threatening to their competitive advantage and reputation [35]. To this end, quality is treated as subordinate to safety [34,50].

3.3. Blocking communicative action

Within the context of non-conformance, it has been observed that managers use their power, in its various guises, to suppress communicative action in the following ways [35]:

(1) **Direct suppression (warnings and intervention):** For example, a project manager requested their contract administrator to ensure that non-conformances greater than a value of 100 000 AUD were not reported at the end of each monthly valuation of works [35]. Instead, the non-conformances were divided up into smaller sums (e.g., < 10 000 AUD), so they were undetectable by senior managers. The project manager argued that, if the truth were known by senior management, they would be formally cautioned and may lose their jobs, as non-conformances were deemed to be a measure of a poorly performing project. In this case, non-conformance requiring rework therefore went underreported and thereby hindered learning from taking place.

(2) **Setting an agenda (manipulating an agenda):** Repeated calls by project managers to senior management to discuss continued understaffing during the mobilization of their projects resulted in works being inadequately supervised during activities such as piling. Errors in the layout of reinforcement occurred, with rework being required. In this case, calls were met with the response that criticisms are only allowable if accompanied by constructive proposals for how to deal with the issue at hand.

(3) **Shaping ideological settings (intentional):** A 'zero-vision' (e.g., no defects) is an ideological framework that is often expressed through a construction organization's culture, which is generally focused on error prevention [6,27,29]. Employees are asked to follow a cliché predicated on "bureaucratic entrepreneurialism" [57, p. 31]. Here, construction organizations claim that, although significant accomplishments have been attained in their work, more is required, as 'zero' has not been achieved, even though they subconsciously know that this goal will never be achieved.

(4) **Production of subject settings (sponsored identities):** A construction organization may introduce a new managerial position into their structure to lead research and development initiatives. The appointed person may adopt the identity of "leader of innovation" [58] or "technological maestro" [59], as it provides them with a sense of self-esteem. When too much emphasis is placed on leadership, it is likely that employees' cognitive capacities will be suppressed, as they are required to passively accept what is presented and needed of them. In this case, employees become followers and subordinates, and critical reflection may be discouraged. Accordingly, employees may become reluctant to

speak up and share their knowledge and experience with errors and rework.

We have the opportunity to learn every day, as new knowledge is captured and skills and attitudes are acquired. Learning is a fundamental survival mechanism of human beings. For construction organizations, the question here is not whether people learn but rather what they learn and how. The responsibility for answering such questions lies within the organization itself. Without the right guidance from an organization's leadership and management, people may learn the wrong things and repeat the same mistakes. In this instance, naïveté prevails, whereby the organization does the same thing over and over, always expecting to prevent rework [60]. This situation is exacerbated when construction organizations solely apply quality-control-orientated principles, which cannot address "conditions of high task uncertainty" within a first-order learning[†] environment [28; 61; 62, p. 537].

All in all, rework is a product of errors and violations committed within an organization's and project's work settings and error culture, and occurs when managers (i.e., actors in positions of influence) attempt to discourage critical reflection that questions sanctioned norms and values. Hence, knowledge of the context in which rework has occurred is required to understand its causation in projects, but previous studies have generally not address this issue.

4. What are the consequences of rework?

Rework can have significant adverse consequences on projects, people, and organizational performance and productivity. Emphasis has typically been placed on the financial impacts of rework, though questions surrounding the accuracy of its estimated direct costs and whether it should include change orders and/or quality issues prevail [25,30,33–35]. When change orders and quality issues are combined, the direct costs of rework have been found to range from 2.4% to 12.4% of a project's contract value [11,18,63,64]. In contrast, when quality issues are only considered under the umbrella of non-conformances or defects, rework costs have been found to vary between 0.05% and 20% of contract value [13,16,65–68].

Studies examining the indirect costs of rework (e.g., idle time, transportation, and waiting time) have been limited. A tentative estimate suggests that these can be as high as six times the direct cost of rework [69]. Indirect consequences of rework include absenteeism, stress, fatigue, disputes, increased insurance cost, reputational damage, and loss of future work [26,69]. The quantification of such consequences is problematic—perhaps even impossible—to determine due to an absence of available data. Indeed, performing rework can naturally invoke a mixture of negative emotions, including anger, anxiety, fear, frustration, ineptitude, helplessness, worry, and the burden of responsibility [70]. It is notable that there has been a scarcity of research examining the negative impact of rework on people's emotional and psychological well-being.

4.1. Impact on organizational profits

Non-conformance costs can directly impact the bottom line of contractors and subcontractors. Again, few studies quantify such impacts, as organizations are generally reluctant to share their rework cost data, due to issues with commercial confidentiality [33,68]. Yet, in a study conducted by Love and Matthews [33], the total loss of profit due to non-conformance requiring rework for a Tier 1 contractor over seven years was revealed to be a staggering 27%. Moreover, Love and Matthew's [33] analysis of 359 projects constructed by the contractor showed that non-conformances requiring rework were required in 210 of them. Of the 210 projects constructed, a mean rework cost of 0.18% of the contract value was identified. More surprisingly, 48% of the total rework costs incurred were attributable to only 42 projects [33]. Thus, contrary to popular belief, not all projects experience rework [33]. Therefore, we question the relevance of claims stating that "average rework costs are 5% of total construction costs," primarily when such figures have been based upon mere 'guesstimates' derived from questionnaire surveys rather than actual costs incurred in projects [17,18].

Determining the costs of rework is not a straightforward process, especially when such costs have seldom been considered a formal key performance indicator by construction organizations in their projects [25,27–30,71]. Moreover, rework data is often located and stored in disparate repositories in projects (e.g., site diaries, non-conformances, site instructions, and punch lists), rendering it complicated to calculate the actual costs and consequences [71]. For example, in a monthly project review report for the construction of a liquified natural gas jetty, made available to us by a Tier 1 contractor, the following comment was made under the heading 'Quality': "The true costs of rework are not being captured, particularly the consequential cost of traveler delays due to cracked welds hold up. Review and record rework costs accurately." Informal discussions with the contractor about this comment in the report reinforced the points we made above. The contractor could only estimate such costs, as there was a high degree of ambiguity with the data, since no formal process had been designed to capture them.

4.2. Impact on safety

Ensuring people's safety during the construction of a project is a constant challenge for organizations. Despite the considerable effort and investment that are put into developing safety-management systems, only marginal reductions[‡] in injuries and accidents have been achieved in Australia, although fatalities have decreased by 53% in the last ten years [72,73]. However, it has been observed that, as a consequence of performing rework, people are more likely to incur an injury [74,75].

Similarly, empirical research reveals that "the association between injuries and rework is significantly strong (ρ = 0.631)," indicating that "63% of the variance in injuries can be attributable to changes due to rework" [76, p. 275]. Tables 3 [6,34,75] and 4 [34,74] provide examples of safety events that have materialized during a rework event. Thus, if construction organizations are to improve safety performance in their projects significantly, they must effectively deal with the errors and violations that result in rework being required [6,22,27,34,35,50,73].

4.3. Impact on the environment

Besides rework having an impact on safety, it can also result in environmental consequences in the form of material waste [77], contamination, and pollution [26]. However, there is a lack of empirical research quantifying the environmental consequences of rework, although examples of specific events can be found in the literature. For example, in a hospital project, it was discovered

[†] Learning within the context of a given problem definition and the analysis of the chosen solution for that problem, while retaining the underlying theoretical insights or deep convictions and values. The feedback loop is represented by using "standards of performance, measuring system performance, comparing that performance to standards, feeding back information about unwanted variances in the system, and modifying the system" [61, p. 289].

[‡] For example, the incident rate has fallen from 17.5 serious claims in 2011 to 15.2 in 2020 [72].

Table 3
Examples of action errors during rework events.

Error type	Safety event	Event description	Sources
Lapse	Unsafe act	A pile needed to be re-drilled from a barge. A Bauer drill on a 280 t crane was used. There was a restricted and limited work area, and long lengths of hydraulic hoses were attached from the drill head to a power pack. Spoil skip bins were also stored on the deck. A task risk assessment had been undertaken and signed off. A rigger attempted to guide the hydraulic hoses up past a spoil bin. The hoses swayed back toward the rigger, trapping the rigger's left hand between the hoses and the underside edge of the spoil bin. The lift was stopped straight away, and the hook was lowered without any resulting injury.	[34]
Slip	First-aid injury	Concrete honeycombing was identified during the construction of a coffer dam wall. Rather than rectifying the defect when it was identified, the project manager decided to complete the wall's construction and rectify the honeycombing later, so as not to delay the project's completion date. While patching on the dam wall, a person fell approximately 34 m down the left-hand abutment to the overflow while attached to a rope fall-arrest system. It was found that the fall-arrest system was not secured to an anchor point and subsequently gave way while the employee was descending the rock face. After the employee presented to the site office for first aid, an ambulance was called and the employee was taken to a hospital.	[34,75]
Mistake	Unsafe act	A person was undertaking rework, as the formwork fold had been missed during the initial installation of a concrete deck. The crew installing the formwork was relatively inexperienced and did the work incorrectly. As a result, the concrete mowing strip did not conform to the required standards. It was necessary for someone to measure the fold in the formwork from the underside of the deck, and this person had to access the formwork frames to reach this area. A person proceeded to install planks to gain access to the work platform. While the fold was being measured, the site supervisor observed that no handrail had been installed through the end rails, although cross-bracing was in place.	[6]

Table 4
Examples of violations during rework events.

Violation type	Safety incident	Event description	Source
Exceptional	Unsafe act	• Subcontractors were tasked to investigate a defective pipe that was leaking. One person, wearing height safety equipment, proceeded to access a roof via an extension ladder. Using an extension ladder, the person ascended to an awning that was 5.1 m above ground level. The person then secured a base plate (anchor), which was then attached to the safety harness, and climbed onto the awning. Subsequently, the person retrieved the ladder and placed it on the awning to access the roof, which was a further 5 m in height. The worker did not utilize the ladder bracket/roof safety-access system that was in place to access the roof, as it was located at the height of 9.5 m, which was deemed to be unsafe.	[34]
		• An employee of a contractor conducted an unplanned task to obtain a level within the base of a manhole for a surveyor who had turned up a day earlier than was initially planned. The employee had propped a ladder against the manhole and climbed to the top. When on top of the manhole, the employee attached a lanyard from their harness to the handrail on a shield, which is an unsafe act when working from a height. A ladder was then inserted into the manhole, and the level was determined by climbing down the top two rungs.	[74]

that asbestos fragments were found in its sealed its roof panels when someone mistakenly cut through one of them. A total of 150 panels had to be replaced causing people to be directly exposed to the contaminated material [78–80]. Likewise, in the same hospital, high lead levels contaminated the drinking water supply. The source of contamination was found to be non-conforming brass fittings that had been installed, which had to be replaced at considerable expense and resulted in the hospital's opening date being delayed by two years [79,80].

5. What can be done to mitigate rework?

The mitigation of rework is an ongoing challenge for construction organizations in their projects [28]. As we mentioned above, rework does not occur in all projects; thus, it is important to comprehend why this is the case. Accordingly, it is necessary to understand 'what went right' instead of looking at 'what went wrong' to address the issue of rework [33,81,82]. Along these lines, we address our final question by drawing on best practices that have contributed to things 'going right' in order to assist in containing and reducing errors and mitigating rework in projects [6,27–30,33–36,39,40,53,54,71].

5.1. Focus on strategic instead of operational solutions

We have seen studies generally propose operational solutions to prevent rework in response to the identification of its proximal and root causes [15–23]. For example, Yap et al. [63] provide nonsensical solutions to reducing rework by suggesting the establishment of a "good communication network" and engaging in "proper production planning," and "proper quality management" (p. 610). Here, Yap et al.'s use of the adjectives 'good' and 'proper' is unhelpful, as these suggestions do not provide a means to improve work practices.

Yap et al. [63] are just one group of many that have succumbed to proposing solutions that make no sense from either a theoretical or practical standpoint. For example, Ye et al. [20] have wryly suggested that, if rework is to be mitigated in projects, then there should be a focus on "effective rework management" in which there is close collaboration between all stakeholders and on "improving the constructability of design through effective communication" (p. 8). But what does "effective rework management" actually mean [20, p. 8]? Rework is the act of rectifying a process or activity that was incorrectly implemented the first time. The error, violation, or change has already happened, so how can the suggestion of "effective rework management" be a solution? It is reasonable to suggest that communication is the key to containing and reducing errors and violations, but Ye et al. [20] overlook the question of how to mitigate rework. Without a doubt, this is a challenge, but improving communication requires an understanding of how information flows in an organization and within projects [71].

Communication is critical for sharing knowledge and experiences about rework, and information flow is indicative of the "quality of the organization's functioning" [83, p. 58]. With this in mind, it is necessary to consider an organization's information flow culture for the following reasons [83]:

- Information is the lifeblood of an organization. However, each organization will differ in how it transfers and utilizes information for decision-making.
- Information flow predicts how an organization is working. Thus, information flow is strong when collaboration and trust are high, which are products of effective teamwork. The Aristotle study at Google found that psychological safety was the critical determinant of team performance [84,85]. When trust is present, people feel that they can have a voice (i.e., speak up) without punishment. If psychological safety promotes speaking up and being heard, then information flow can be used as an indicator of trust [36,74,83].
- Information flow reflects the style of leadership that is in place. Pathological leaders desire to succeed, often creating a "'political' environment for information that interferes with good flow" [83, p. 58]. In such cases, we often see the blocking of communicative actions, as identified above (Section 3.2). Bureaucratic leadership places emphasis on achieving success in a particular area of an organization, while focusing on rules and regulations. In contrast, with "generative" leadership [83], there is a focus on the organization's mission and on providing recipients with relevant, timely, and transparent information.

We have only scratched the surface of information flow culture here and will delve a little deeper below when we draw on the best practices used to reduce rework in projects. Needless to say, a plethora of techniques, tools, and technologies have been propagated as solutions to reduce errors, change orders, and improve integration, constructability, information exchange, production planning, and cost control in projects, including the Construction Industry Institute's Field Rework Index [15], building information modeling (BIM) [70,86–89], systems information modeling (SIM) [90], Lean principles, Last Planner® [91], and reference class forecasting [92], to name a few. Such techniques, tools, and technologies—some of which are prescriptive—are used to automate processes, implement tighter controls and procedures, increase supervision, and de-bias risk. Still, rework occurs because organizations have focused on operational issues instead of the strategic solutions needed to establish the working conditions within which projects are procured [36].

5.2. From little things, big things grow: Building an error-mastery culture

Over the last 25 years, there have been calls for cultural change from the public and private sectors to improve the performance and productivity of construction projects [93–98]. Put simply, culture involves the pattern of thought, emotion, and action that can shape how an organization responds to problems [99]. Culture has been defined as follows:

> *. . .a pattern of shared basic assumptions learned by [an organization] as it solved its problems of external adaptation and internal integration, which has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems* [100, p. 18].

Changing the culture of construction has been and continues to be a challenge [36]. Be it as it may, changes to work practices are being enacted, even though progress has been sluggish [96,98] to say the least, particularly in terms of how errors and violations are viewed and dealt with by organizations [29,31,34,36,45].

As mentioned earlier, the notion of error prevention governs the mindset of most construction organizations, with error-making being viewed as an unhealthy sign of poorly performing projects (Table 1). The Get It Right Initiative (GIRI)[†] in the United Kingdom aims to "improve construction productivity and quality by eliminating error" and creating an "error-free culture." Despite the best intentions of the GIRI, their error-elimination strategy is somewhat counterproductive; it will likely impede learning and innovation from taking place if the initiative continues to solely focus on error avoidance.

In volatile, uncertain, complex, and ambiguous (VUCA) [101] environments such as construction, people "are likely to commit a greater number of errors, as they are required to make decisions frequently and faster" [102, p. 531]. The GIRI's choice to focus on eliminating errors is understandable, as errors have negative implications. But people will naturally make errors, considering the nature of the work environment within which construction projects are delivered [2]. Thus, construction organizations must constructively deal with errors, as they cannot be eliminated [32,41]. As the English poet Alexander Pope reminds us, "to err is human" [103].

5.2.1. Error management: Accepting that errors happen

Our observations from several large-scale infrastructure projects (e.g., transport and water) procured using an alliancing[‡] delivery method revealed that an acceptance that 'errors happen' and the implementation of an error-management orientation is being played out in practice [6,27–29,34,71,74,75]. In essence,

> *. . .error management involves coping with errors to avoid negative error consequences, controlling damage quickly (including reducing the chances of error cascades[††]), and reducing the occurrence of particular errors in the future (secondary error prevention) as well as optimizing the positive consequences of errors, such as long-term learning, performance, and innovations* [32, p. 665].

The adoption of error management "creates an openness about errors, which may facilitate error detection" before its escalation [102, p. 532; 104]. In Table 5 [32], we identify the processes and outcomes of embracing error management that were observed to materialize during these construction alliance projects [27,29].

For readers unfamiliar with the alliance procurement approach, we will briefly identify its key characteristics. Still, explaining the detailed workings and the pros and cons of such alliances lies outside of the scope of our paper. Thus, we suggest that readers refer to the work of Walker and Rowlinson [105], who contextualize and thematically explore the concept of alliances, emphasizing its theoretical foundations and practical application.

Alliance contracting is relationship-based and is characterized by a culture of collaboration and cooperation between parties that are working together to deliver a project. The parties of an alliance are usually the purchaser of services (the owner) and one or more service providers or non-owner participants, such as head contractors and operators. The parties' interests are aligned, and risks are shared through incentives offered by the owner that depend on how well the project is delivered, as measured against the agreed-upon objectives. Alliances are characterized by a 'no blame, no fault' culture, enabling them to "deal with errors and their consequences positively" [28, p. 5]. Moreover, alliances promote "collaboration, knowledge sharing and organizational learning" [106, p. 229].

The organizational practices typically used to support error management are [37]: ① communicating about errors; ② sharing error knowledge; ③ helping in error situations; ④ quick error

[†] The GIRI is a group of industry experts, organizations, and businesses dedicated to eliminating error and improving the United Kingdom construction industry. Details can be found at https://getitright.uk.com/.

[‡] Alliances are akin to integrated project delivery.

[††] In this case, an error leads to another error occurring; a knock-on effect materializes [27, p. 6].

Table 5
Processes and outcomes of error management (errors are inevitable).

Before an error	After an error	Interpersonal process	Outcome
• Anticipating errors • Preparing for errors • Routines to deal with errors	• Error detection • Quick response to mitigate the negative consequences of errors • Secondary error prevention	• Open communication about errors • Help in dealing with errors • Sharing error knowledge	• Learning • Performance improvement • Innovation • Individual proactiveness

Adapted from Ref. [32, p. 666].

detection and damage control; ⑤ analyzing errors; and ⑥ coordinating and effective error handling. The alliances we have studied were found to display all these practices, although they were subconsciously enacted [27–29]. Without the leadership's orientation toward error management, such organizational practices could not have been effectively performed [102].

In our alliance studies, we observed the leadership to be authentic, which has helped shape the way errors were handled [27–29]. In accord with Westrum's generative leadership style [83], the authentic leadership adopted within these alliances led with purpose and followed set values and 'best-for-project' principles. Moreover, the leadership was underpinned by an ethos of collaboration and transparency, a drive to cultivate trust, and a willingness to demonstrate excellence through self-discipline.

Encouraging people to speak up about errors openly in construction projects is an ever-present challenge, as they are often fearful of being blamed, or made to feel embarrassed about their (in)actions. Cognizant of this issue, the studied alliances' leadership worked tirelessly to promote and engender an environment of psychological safety within its project teams and subcontractors [27–29,107]. For example, in the case of the Barwon Water Alliance (BWA), regular rework forums were held with the project team and subcontractors to jointly share experiences with rework and learn together. The forums aimed to stimulate curiosity, solicit questions about prevailing work practices, promote positive dialogue and discussion, and provide a safe place to own up to mistakes and rework [108]. In addition, 'lessons-learned' workshops were performed after every project; these were shared with all subcontractors, with new ideas being sought to improve the delivery process and reduce rework [108]. Onsite supervisors relied on 'toolbox talks' to encourage subcontractors to speak up, anticipate what could go wrong and, in doing so, raise awareness of the risk of rework and its impact on safety [27–29].

While these alliances were highly effective in communicating and sharing knowledge about errors, they struggled to analyze their rework effectively, as they did not have the necessary information architecture and systems to capture and consolidate such data [71]. Even so, there was a consensus among the alliances' project teams and subcontractors that their rework incidents were considerably fewer than in projects delivered using other procurement methods [27–29,107].

Alliances provide an environment to facilitate error management and effectively attend to errors and rework. Developing a mindset that 'errors happen' and engaging and enacting the organizational practices of error management provide a foundation for mitigating rework. We provide a caveat here, as error management has only been observed to exist in alliance projects. The extent to which error-management practices are adopted—if at all—in projects delivered using conventional procurement methods (e.g., design-and-construct and traditional-lump-sum) and private (e.g., build-own-operate-transfer and public–private partnerships) participation in infrastructure forms remains unknown. However, based on our previous study of a Tier 1 contractor's projects, which excluded alliances, we have only observed the presence of an error-prevention orientation toward the handling of errors [35].

At this juncture, it is also necessary to address the issue of dealing with violations. As explained earlier, violations only occur because rules exist; however, they have tended to evolve "as a reaction to errors on some prior occasions" [32, p. 679]. Thus, Frese and Keith [32] propose using violation management like error management for treating violations. Here, violation management commences "after a violation has occurred" and aims to avoid "negative consequences altogether" or reduce its negative consequences [32, p. 679]. Violation management has yet to be examined in depth within normative literature, particularly in the context of quality deviations and rework. Despite this, we incorporate violation management when reference is made to error management in this paper.

5.2.2. Moving error management to an error-mastery culture

The concepts of error management and psychological safety complement each other—although they also stand on their own merits—as approaches to dealing with errors. An error-management culture focuses on how individuals and teams act upon errors, while psychological safety focuses on what individuals in teams experience emotionally [32,37,109]. Significant progress toward rework mitigation can be made when authentic leadership supports error management and psychological safety [27]. This is not to say that work practices such as those based on Lean principles (e.g., visual management, Last Planner®, work standardization, and construction process analysis), for example, do not play a role in containing and reducing errors; quite the contrary. But when such practices are applied in an environment governed by an error-prevention focus and when psychological safety is absent, the reporting of rework is eschewed, costs are covered up, and learning opportunities are lost [27].

Thus, in this case, error prevention can be metaphorically compared to a tree. Like a tree, only part of the solution to rework can be seen; that is, only the trunk, branches, and leaves of a tree are visible, which can be compared to the techniques, tools, and technologies used to typically prevent its occurrence. Yet, like a tree, the root system namely, leadership, error management, and psychological safety—that provides structure and function to combat rework is hidden from view. Yet, this same root system (i.e., strategic solutions) has been overlooked when determining how to mitigate rework.

While authentic leadership, error management, and psychological safety form the metaphorical roots that provide the conditions necessary to mitigate rework, Love and Matthews [29] suggest that organizations can do more to address this problem by building resilience to error. Thus, as shown in Fig. 2 [110,111], Love and Mathews [29] have proposed a new theoretic, referred to as the 'error-mastery culture,' to respond to and recover from errors and to build resilience in organizations and projects, making it possible to better transform lessons from the past into future success.

Resilience is introduced to help organizations and projects "cope with whatever anticipated harms might emerge" [112, p. 220]. The risks of errors and violations are speculative, and construction organizations "cannot know which possible risks [and uncertainties] will" arise [44, p. 165]; thus, it makes sense

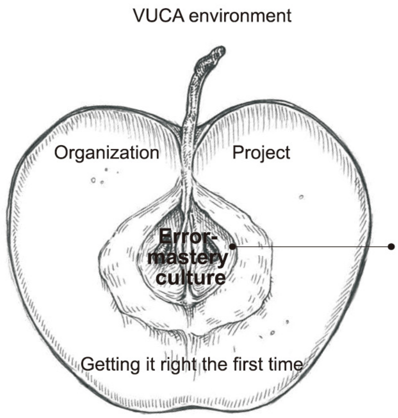

Fig. 2. Core components of an error-mastery culture.

to incorporate the dimension of resilience into Love and Mathews [29] error-mastery culture theoretic. There are three elements to resilience that can enable organizations to anticipate failure, learn how to adapt to circumstances where failure is indicated, and restore conditions after an event [111, p. 257; 113]:

- **Foresight:** the ability to predict something bad happening;
- **Coping:** the ability to prevent something bad becoming worse;
- **Recovery:** the ability to recover from something bad once it has happened.

To demonstrate the application of these elements in practice, we use as an example daily pre-start meetings involving members of a contractor's site management team and subcontractors operating at the sharp-end of construction. Pre-start meetings are undertaken before work commences onsite and provide an opportunity to ensure that the entire workforce is fit for duty. Such meetings are interactive and help focus the workforce on the activities to be performed; quality and safety issues are also discussed. Table 6 [111] presents a scenario in which these elements arise when an error has occurred and rework is required. This scenario briefly exemplifies an observation from our empirical studies.

6. Research implications

While addressing our three research questions, we have reviewed the literature and referred to our empirical studies identifying absences of knowledge and areas of limited knowledge that require further lines of inquiry. For example, to fully address our first question related to causation, it is necessary to acquire a more in-depth understanding of pathogenic influences and the incubation periods of errors that may result in rework or failure. The longer the incubation period of an error, the greater its negative consequences [4,5].

A case in point is the I-W35 Minneapolis Bridge collapse in 2007, which killed 13 and injured 145 people. The US National Transportation Safety Board [114] determined that the probable cause of the collapse of the I-W35 bridge was the "inadequate load capacity, due to a design error of the gusset plates" (p. xiii). This design error had gone through a period of incubation lasting over 40 years.

To reiterate, we possess limited knowledge about the consequences of rework, as researchers have had limited access to actual project-related data due to issues of commercial confidentiality. Nevertheless, although rework has traditionally not been quantified by construction organizations, it is now being given serious consideration in light of its impact on safety.

A major challenge facing construction organizations, hindering their ability to capture and consolidate their rework data and use it for risk analysis and benchmarking, is the absence of an ontology[†] for decision-making purposes [71]. However, creating an ontology is a complex task. In the context of rework, it requires researchers and construction organizations to work collaboratively to define the links between different types of semantic knowledge (e.g., define a common vocabulary) and formulate the search strategies needed to address rework-related queries for decision-making.

The error-mastery culture proposed by Love and Matthews [29] provides a bourgeoning theoretic for reducing and containing errors (violations) and mitigating rework and safety incidents. However, more research is required to understand its operationalization to practice beyond alliance contracts. In Australia and New Zealand, for example, alliances are only being used to deliver a fraction of the total capital expenditure of projects, with public–private partnerships and conventional procurement methods dominating the infrastructure market [115]. Thus, is it possible for an error-mastery culture to be nurtured in such procurement environments, which are prone to becoming adversarial, as contractors' margins are often stretched due to taking on too much risk [116,117]? It is this very question that future research should seek to address.

7. Practical implications

While additional research is required to examine the operationalization of an error-mastery culture beyond alliances, the implications for practice that emerge from this research are three-

[†] An ontology is a skeletal framework for knowledge. It encompasses a representation, formal naming, and definition of the categories (e.g., errors and violations), properties, and relations between the concepts, data, and entities.

Table 6
Resilience in practice: foresight, coping, and recovery.

Scenario: One day at a pre-start meeting, a supervisor explains to the workforce that a significant concrete pour is planned late that afternoon. However, there are problems with the reinforcement's layout, and it needs to be rectified before the pour can commence. The supervisor raises a request for information (RFI) on Friday afternoon to determine whether the installed reinforcement layout can be left as is, even though it slightly differs from that design. The consequences of this situation are the added pressure placed on the workforce and the potential for safety incidents to arise. If the pour is held up, then there is a potential for the project to be delayed.

Resilient element	7:00 Monday Foresight "The ability to predict something bad happening"	12:00 Monday Coping "The ability to prevent something bad becoming worse"	17:00 Monday Recovery "The ability to recover from something bad once it has happened"
Individual	For example, the supervisor calls structural engineering, requesting an answer to the RFI.	For example, the supervisor decides to instruct the workforce to rectify the reinforcement as per the original plan.	For example, the supervisor makes sure the work progresses and assures subcontractors that they will not be impacted.
Micro	For example, the supervisor identifies workforce shortages due to COVD-19.	For example, the supervisor determines that safety performance could be jeopardized, as the workforce works to a fixed timeline with resources. Additional resources are added to help supervise and rectify works.	For example, the supervisor reviews the workforce situation checking for fatigue and well-being and then prepares for the next day's work activities.
Macro	For example, lessons learned from previous projects are shared and discussed.	For example, the supervisor communicates with subcontractors likely to be impacted and works with them to minimize delays and productivity impacts.	For example, review the progress of the day's events and impacts and how it was managed. Discuss with the subcontractor how things could have been handled better.

Adapted from Ref. [111, p. 258].

fold. First, re-calibrating an organization's cultural orientation from error prevention to error management will be a challenge, as a project's procurement approach and the dynamics of negotiated order[†] [118,119] will influence its effectiveness. However, construction organizations need to accept that errors and rework will happen. They also need to measure the costs and consequences of thier rework and raise awareness about its presence in projects. Previous research indicates varying "conventions through which, and the outcomes for which different types of errors" are communicated in practice [120, p. 502]. Thus, organizations should use various mediums (e.g., digital form using alerts and word of mouth at daily pre-start meetings) to communicate knowledge of rework events across their projects to their site management. This will enable them to anticipate and plan for 'what might go wrong' before tasks commence onsite and is particularly important because there is an increased likelihood that a safety incident will occur while performing a rework event (Table 2 [35,52,53]).

Second, to support the ability to anticipate 'what might go wrong,' construction organizations need to ensure that psychological safety is supported and promoted throughout their projects [27,34,50,74]. In doing so, interpersonal risk-taking (e.g., openness to report errors) can be established, as well as a practice of 'learning through' rather than 'learning from' the errors that occur [50]. Accordingly, the processes of error-making and handling are "elevated to being a part of the way we do things around here" [50; 121, p. 422]. Finally, construction organizations can learn from the experiences and practices used to reduce and contain errors in the BWA [27,108]. One of the notable practices introduced by the BWA was knowledge-sharing workshops undertaken with subcontractors to discuss quality issues and seek their views on how these could be reduced. During such workshops, all parties were encouraged to openly and constructively voice their quality-related concerns and, in doing so, stimulate an exchange of ideas and the sharing of experience.

[†] A negotiated order is the pattern of activities emerging over time as an outcome of the interplay of the variety of interests, understandings, reactions, and initiatives of the individuals and groups involved in an organization (or project) [118]. Accordingly, Strauss [119] asserts that "the negotiated order on any given day could be conceived of as the sum total of the organization's rules and policies, along with whatever agreements, understandings, pacts, contracts, and other working arrangements [are] currently obtained. These include agreements at every level of organization, of every clique and coalition, and include covert as well as overt agreements" (p. 5 and 6).

8. Conclusions

Rework can contribute to a project's misperformance. Yet the literature, in its quest to determine rework causation, has tended to ignore errors and violations and how the working environment in which people work fuels their occurrence. The corollary to this lack of knowledge is the absence of a theoretical framing to examine rework causation, which has hindered scholars' ability to develop solutions that construction organizations can utilize to improve the performance of their projects. Instead, studies have adopted an over-simplified and reductionist view by focusing on proximal and root causes, which—as we have argued here—has resulted in the propagation of artificial solutions with no relevance to practice.

This paper shifts the extant discourse about rework beyond previous parochial reviews. It draws upon our previous empirical studies, among others, to provide a much-needed theoretical framing to better understand why rework occurs, what its consequences are, and how it can be mitigated during construction. Our review reveals that the causes of rework are attributable to a series of so-called 'pathogens,' although few studies have examined their nature in construction. Even though rework can adversely impact project costs, safety, productivity, and the environment, we are none the wiser about how realistic the existing estimations of these are, as researchers have had limited access to construction organizations' data.

An abundant number of techniques, tools, and technologies are deployed in construction to reduce rework. However, these tend to focus on a project's operational aspects rather than on how the environment in which people work influences their actions and decision-making. We suggest an error-mastery culture theoretic that comprises authentic leadership, psychological safety, an error-management orientation, and resilience. This approach provides a foundation from which construction organizations can begin to effectively address rework in their projects, enabling them to be better positioned to realize the benefits associated with the techniques, tools, and technologies espoused to address rework, which include Lean principles, the Last Planner®, and building information modeling. Finally, we provide directions for future research and identify implications for practice so that strides forward can be made in rework mitigation during construction.

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Compliance with ethics guidelines

Peter E.D. Love, Jane Matthews, Michael C.P. Sing, Stuart R. Porter, and Weili Fang declare that they have no conflict of interest or financial conflicts to disclose.

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