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Error aversion or management? Exploring the impact of culture at the sharp-end of production in a mega-project

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ABSTRACT

The research we present in this paper addresses the following question: *What type of error culture does the rank-and-file workforce experience during construction, and does it help mitigate rework?* We undertake an exploratory case study of an Alliance, which forms part of a transport mega-project. An error culture questionnaire is administered to the Alliance's subcontractors' workforce across four projects. We find that an error management culture positively correlates with reductions in rework and holds a divergent relationship with an error aversion culture. We further reveal a negative association between an error aversion culture and the ability to reduce rework. Consequently, we question the contemporary wisdom that assumes that error prevention should be combined with error management to create an adaptive culture, aiming to minimise the negative and maximise positive error consequences. We finally discuss the study's limitations and implications for future research examining error culture in construction projects.

1. Introduction

> "It is human to err; and the only final and deadly error, among all our errors, is denying that we have ever erred" G.K Chesterton

Chesterton's words remind us of the importance of errors as they are fundamental to human and organisational development. Making errors and trying something new to improve is necessary for learning and innovation (Van Dyck et al., 2005; Goodman et al., 2011; Hofmann and Frese, 2011; Frese and Keith, 2015). Companies that deliberately rely on errors as a source of feedback and improvement in product development include 3 M and IDEO (Naveh and Lei, 2019). Indeed, it is the very nature of error-making that leads to the process of scientific advancement as it is wholly reliant on "eliminating wrong approaches in the sense of falsificationism" (Frese and Keith, 2015: p.663).

While we can acknowledge and appreciate the importance of errors, by the same token, they also arouse a great deal of trepidation as they can result in negative consequences (Van Dyck et al., 2005). Therefore, an organisation's natural response to errors is to enact an error prevention strategy, emphasising error eradication (Frese, 1991). The upshot is an organisational mindset where "errors can and need to be prevented (zero tolerance)" (Frese and Keith, 2015: p.666), nowhere more so than in construction, where the errors contribute to poor quality performance (e.g., non-conformances and rework) are measured by the absence of negative consequences (Love et al., 2021a). Thus, quality performance is high when the number of non-conformances, defects and the like is low. The drive for quality is then epitomised by "zero errors, zero defects, zero rework and zero surprises" as perfection is needed at every level of the production chain (Spencley et al., 2018: p.1).

A cursory view of the construction and engineering literature reveals that errors have received some attention though emphasis has been placed on preventing rework (Love et al., 2021a). However, within the cognitive science, organisational behaviour and psychology literature, research suggests that error prevention needs to be supplemented by error management – "an approach directed at effectively dealing with errors after they have occurred, with the goal of minimising negative, and maximising positive consequences" (Frese, 1991; Van Dyck et al., 2005; Frese and Keith, 2015: p.661). An error management approach assumes that human errors cannot be prevented, and thus it is "necessary to ask the question of what can be done after an error has occurred"

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(Van Dyck et al., 2005: p.1228).

Error management can be conceptualised in a similar way as to stress management — "an approach that does not aim at changing the stressor itself but rather focusing on how to change individuals' responses to these stressors to reduce their negative consequences" (Murphy, 1996; Van Dyck et al., 2005: p.1228). Error management accepts that errors happen and deals with their consequences after they have occurred. Rework is an error response and can be simply defined as "the unnecessary effort of re-doing an activity or process that was incorrectly implemented the first time" (Love, 2002: p.19).

The vocabulary used to examine rework in construction is somewhat inconsistent and ill-disciplined, which has resulted in its causes and actual costs being difficult to determine (Love and Smith, 2019). However, studies examining rework costs in construction projects have been reported to range from less than 1% up to 20% of contract value (Barber et al., 2002; Li and Taylor, 2014; Love and Matthews, 2020). Irrespective of the inconsistencies in the definitions of rework and methods used to determine its costs, it is nonetheless a pervasive problem that confronts practice. In addition to the negative financial impact of rework on an organisation's project costs and bottom-line, research has also demonstrated that rework has an association with safety incidents (Love et al., 2018a; b;c), indicating that, if we reduce rework, safety performance will significantly improve (Wanberg et al., 2013; Love et al., 2018c).

Putting effort into containing (i.e., measures designed to enhance detection and recovery from errors and minimise adverse consequences) and reducing (i.e., measures designed to limit its occurrence) errors in construction projects requires a culture adept to dealing with them. But, by focusing solely on error prevention, construction organisations limit their ability to learn and reduce their rework (Dekker, 2017; Love and Matthews, 2020).

Research examining error culture in construction has been limited to projects procured using Program Alliances and their members[1] where error management practices have unconsciously been displayed (Love et al., 2018b, 2021a). However, subcontractors and their rank-and-file workforce's views of a project's prevailing error culture have never been empirically examined. After all, this workforce operates at the sharp-end of construction and therefore experiences first-hand the errors that can require rework. Our paper, therefore, aims to contribute by filling this void and addressing the following research question: *What type of error culture does the rank-and-file workforce experience during construction and does it help mitigate rework?*

In this paper we build on our previous exploratory research, which focused on the Non-owner Participants (NoP) of an Alliance (i.e., design engineers and constructor) (Love et al., 2022) and focus on subcontractors and their rank-and-file workforce perceptions of error culture. We commence our paper by introducing the theoretical underpinning for the research. Then, we present a case study of a mega-transport project, which provides a setting to examine our research question using Van Dyck et al.'s (2005) error culture instrument. The results of our study are then presented. We next discuss our results identify the paper's limitations, contributions and implications for future research before submitting our conclusions.

[1] Alliance contracting is relationship-based and characterised by a culture of collaboration and cooperation between the parties delivering a project. The parties to an alliance are normally the purchaser of services (the owner) and one or more service providers or non-owner participants such as head contractor and operator. The parties' interests are aligned and risks are shared through incentives offered by the owner for how well the project is delivered, as measured against agreed objectives. Three core principles underpin alliances: (1) an integrated project team; (2) best-for-project focus with a no-blame culture; and (3) Risk-reward payment model (i.e., gain-share/pain-share regime).

2. Theoretical development

Errors can result in the need for rework during construction (Love et al., 2021a; b). Like rework, defining errors is difficult as they can materialise from individuals, teams and organisations and from actions and inactions, as well as judgement and decision-making (i.e., which arise due to cognitive biases and heuristics (Senders and May 1991; Sasou and Reason, 1999; Weber and Johnson, 2009; Goodman et al., 2011; Li et al., 2016). In this paper, we are concerned with individual action errors, which represent an "unintended deviation from plans, goals, or adequate feedback processing as well as an incorrect action" (Van Dyck et al., 2005: p.1229). Our definition of action errors is broader than that propagated by Van Dyck et al. (2005) as we drop "that results from a lack of knowledge" (p.1229) as errors may also occur due to cognitive failures (i.e., slips and lapses, which are failures of execution) and mistakes (i.e., a wrong intention is formed) (Reason, 1990). What is key here is that the committed error is unintentional.

We acknowledge that violations, which are "a conscious intention to break a rule", can also result in rework, but we will not address this issue in our paper (Love et al., 2009; Frese and Keith, 2015: p.663). Also, Frese and Keith (2015), in their definition of a violation, incorporate the phrase "or to be non-conforming to a standard" (p.663). However, a non-conformance can arise in construction due to a mistake or slip and may require rework to assure conformance to a specified standard (Love et al., 2018c). Thus, we do not consider a non-conformance to be a violation.

While individuals are prone to making errors, the organisational conditions within which people work often influence and exacerbate their occurrence (Reason, 1990; Love et al., 2009; Goodman et al., 2011; Lei et al., 2016; Naveh and Lei, 2019). However, the error-prone approach that prevails in an organisation "applies to the development of its culture" (Frese and Keith, 2015: p.662). Thus, an organisation's culture develops through its subsequent dealings with past errors and mistakes that result in the emergence of new problems and, when resolved, can "propel its development further" (Festinger, 1993; Frese and Keith, 2015: p.622).

An organisation's culture generates a system of shared norms, values and a set of common practices (Van Dyck et al., 2005) "through a process of socialisation; that is, the way we do things around here" (Love and Smith, 2016: p.422). How people handle errors within an organisation is then a product of its prevailing culture. Previous research identifies two error handling strategies that form the basis of an error culture (e.g., Frese, 1991; Chillarege et al., 2003; Bell and Kozlowski, 2008; Van Dyck et al., 2005; Dimitrova et al., 2015; Dimitrova et al., 2017: Frese and Keith, 2015): (1) error prevention, which focuses on preventing the occurrence of errors in such a way as not to suffer their negative consequences; and (2) error management, which accepts that errors happen and puts effort into minimising their negative consequences. Practices of error management include (1) communicating about errors; (2) sharing error knowledge; (3) helping in error situations; (4) quick error detection and damage control; (5) analysing errors; (6) coordinating error handling; and (7) effective error handling (Van Dycke et al., 2005). We now take a closer look at these two error-handling strategies.

2.1. Error prevention and error management

A question that pervades the organisational and behavioural psychology literature is whether organisations should adopt error prevention, error management or both in their quest to address errors (Frese, 1991; Dimitrova et al., 2017). Traditionally, organisations have focused on error prevention, no more so than in construction. But, Frese (1991) has suggested that "error prevention should be complemented by the strategy of error management" (p.776). Fig. 1 conceptualises the relationship between error prevention and error management.

Despite all the effort put into preventing errors (i.e., blocking erroneous actions, including goal-oriented behaviours and communication

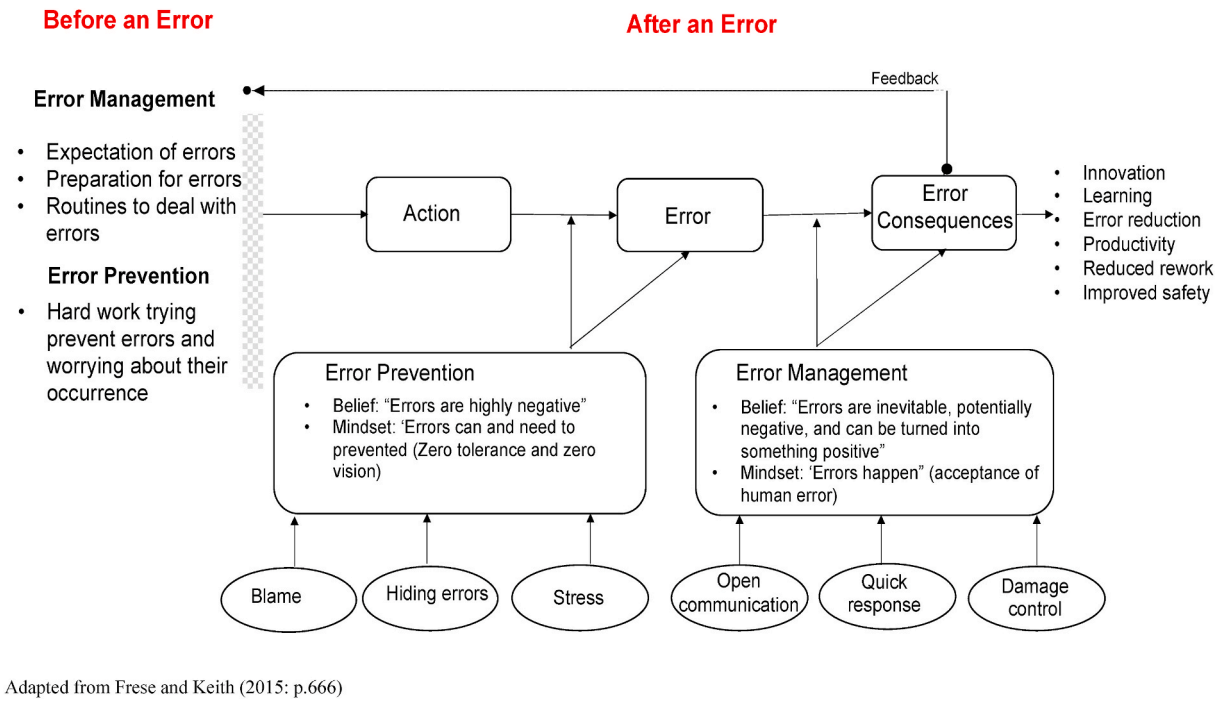

Fig. 1. Conceptualising error prevention and error management.

acts), they will materialise (Frese and Keith, 2005: p.665). Thus, it is impossible to reduce errors to zero. However, even though this is the case, we often see construction organisations shaping their ideological settings for quality and safety by implementing a 'zero-vision' strategy (i.e., defects and accidents) (Love et al., 2021a; b). In this instance, those working on-site are asked to follow a cliche predicated on "bureaucratic entrepreneurialism" (Dekker, 2013: p.31).

Here, construction organisations can claim that significant accomplishments in their work have been attained, but more is required, as zero is not achieved, despite knowing subconsciously that it never will. Yet, considerable effort is made to prevent errors through engaging in control-orientated principles, particularly in the context of quality, (1) increasing control and reliability (e.g., supervision); (2) exploiting existing skills and resources; (3) first-order learning[2]; and (4) monitoring and assessing known customer needs. Nonetheless, a singular emphasis on quality control is not "suited to conditions of high task uncertainty", yet such settings form an innate feature of construction (Sitkin et al., 1994: p.573).

As mentioned above and depicted in Fig. 1, error management commences after an error has occurred and requires organisations to focus on coping with errors to avoid negative consequences. Thus, organisations need to control any potential damage as quickly as possible (including any likelihood of error cascades) and reduce the occurrence of future errors (i.e., secondary prevention). Therefore, errors provide learning opportunities as organisations can better position themselves to anticipate 'what might go wrong' and implement routines to deal with errors when they arise (Westrum, 2014; Love and Matthews, 2020).

Rather than learning from errors, which is instigated by having in place error correction mechanisms, error management enables organisations to engage in 'learning through', emphasising how to handle errors (Love and Matthews, 2020; Love et al., 2021a). Thus, error management is aligned with the learning-oriented principle of quality whereby emphasis is placed on issues such as: (1) actively searching for new customers, testing and developing new services and products; (2) stressing improvement in learning capability by exploring new skills and resources and resilience; and (3) second-order learning, that is the rethinking of dominant mental and action models, particularly of theoretical insights and deeply rooted values and convictions.

Intuitively, while error prevention is not negative *per se*, solely focusing on error prevention has been linked to negative outcomes such as hiding errors, error cascades, lower psychological safety within teams and poor performance (Edmondson, 1996, 1999; Van Dyck et al., 2005). Research undertaken by Dimitrova et al. (2017) reveals that error prevention "dampens task-focus and adaptive transfer performance, as well as amplifies negative self-evaluative off-task thought" (p.669). Contrastingly, error management, compared to error prevention, has been found to have positive effects on people, such as lowering frustration, providing stronger emotion control, improving motivation and cognition (Chillarege et al., 2003; Dimitrova et al., 2017). Hence, "error management dampens worry and boosts one's perceived self-efficacy (Dimitrova et al., 2017: p.669). While error prevention is maladaptive (Loh et al., 2013), the high-reliability organisation literature suggests that its combination with error management can create a more adaptive culture as people need to balance both perspectives when performing activities (Weick and Sutcliffe, 2007; Goodman et al., 2011; Frese and Keith, 2015).

3. Case study

Due to the research context's novelty and the limited number of studies to date that have examined error culture in construction, particularly through the lens of a subcontractor's rank-and-file workforce, an exploratory case study approach was adopted to determine the prevailing error culture orientation on-site and its influence on rework. Thus, case research is particularly germane to research questions "for which there is little conflicting theory and/or empirical evidence, and so no obvious answers" (Einsenhardt, 2021: p. 149).

[2] 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 with standards, feeding back information about unwanted variances in the system, and modifying the system" (Green and Welsh, 1988, p.289).

Our research purports to determine the type of error culture present on-site and its influence on rework (Van Dyck et al., 2005; Frese and Keith, 2015). In line with Love et al. (2022) we adopt Robinson-Fayek et al.'s (2004) definition of rework where it is "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 off-site manufacture" (p.1078).

We have opted for a single, deductive, and quantitative case study in this research, as it is appropriate when it comes to 'extreme exemplars' in a unique' or idiosyncratic setting (Yin, 1984; Einsenhardt, 1989, 2021). We build on the error management work conducted by Love et al. (2022) and apply Van Dyck et al.'s (2005) error culture instrument to subcontractors operating at the coalface of construction.

The unique setting for our research (Einsenhardt, 2021), or what Siggelkow (2007) calls a *talking pig*,[3] is a transport mega-project, a program of works initiated by a State Government to remove existing and install new road and rail infrastructure throughout the metropolitan area of a major Australian city. The project is being delivered using a Program lAliance delivery strategy. Several Alliances have been established to complete a series of projects. The scope of work includes removing existing and constructing rail and road infrastructure. The research focuses explicitly on one of the Alliances with which we are actively involved with its continuous improvement initiative (ConIP). The ConIP mainly focuses on examining how rework and its associated wastes in the Alliance can be reduced, as it strives to stimulate learning, innovation and improvement in the program's work packages (i.e., 'projects'). Due to the project's political sensitivity, we cannot provide details about its characteristics.

No rework measurement is undertaken *per se* due to the absence of standard terminology and an integrated information system to record and document its costs and causes. However, design changes and errors in the Issue for Construction (IFC) drawings and non-conformances have resulted in rework during construction, which are issues the Alliance is actively seeking to reduce. Furthermore, Alliance representatives have a mindfulness that many errors requiring rework may not be captured at the sharp-end of construction. Such a mindfulness adds to the suitability of the single case setting for this research (Yin, 1984; Barratt et al., 2011). Therefore, acquiring a baseline of error culture on-site provides an indicator of prevailing shared values and norms and the effectiveness of practices and procedures to mitigate rework. Accordingly, a questionnaire is used to assess the project's cultural orientation. Further, there were some informal discussions with subcontractors to gain additional insights.

3.1. Sample and procedures

We initially sought to solicit subcontractors' views about the existing error culture within the Alliance, as they operate at the sharp-end of construction, using a questionnaire survey over two weeks in January and February 2021. The Alliance had completed four projects, and at the time of administering the survey, another four were under construction (Fig. 2). To ensure the sample is representative and reduce an over-reliance on hindsight bias (Mark and Sutton, 1997), we invited the workforce of all subcontractors involved with removing existing and installing new infrastructure to participate in the study.

As denoted in Fig. 2, a Superintendent during the daily toolbox talks explained to the site workforce the study's aim and purpose at each of the four sites sampled. This endorsement on the part of the Alliance helped increase our credibility as researchers in the respondents' eyes but held little bearing on the research results as they responded to an online questionnaire survey held on a remote server. A series of Quick Response (QR) codes were placed around the offices of each site, which provided a direct link to the survey, developed using Qualtrics, making it accessible via the Internet through mobile devices.

A total of 91 responses to the questionnaire were received from the site workforce. While the sample of 91, on face value, may appear small, it does provide us with a snapshot of the prevailing sentiment about errors and rework. As Barratt et al. (2011) note, case studies differ from sampling units in inferential statistics. Case studies (theory-testing) are instead idiosyncratic studies. In other words, "lack of generalisability to the sampling population is not of main concern. What is important is the contextual data from case studies that are used to confirm or falsify a theory" (Barratt et al., 2011: p. 332).

Notably, only a limited workforce was allowed on each of the four sites due to the social distancing restrictions that had been enacted due to the Corona-Virus 2019 (COVID-19) pandemic, which hindered our response rate. While we only distributed the survey to subcontractors on the four live sites, we received three responses that did not specify the site they were working on. However, these three responses have still been included in our sample. The unit of analysis in our study is the Alliance, but to recap, we focus on the error culture on-site for each of its projects.

3.2. Measures

The questionnaire survey comprised of three sections: (1) background information (i.e., functional area and location); (2) rework performance and goal achievement; and (3) error culture. We initially asked respondents to determine the extent to which rework was reduced once drawings had been IFC and how design requests and non-conformances influenced its occurrence.

To examine the Alliance's current ability to reduce rework and compare its level with other projects, we introduced the construct of rework goal achievement. To this end, 'Rework Goal Achievement' was measured using two items based on a five-point Likert scale ranging from '1' (Not at all) to '5' (Completely agree): (1) the Alliance's success in reducing rework in construction compared to other projects respondents had been involved with; and (2) the success of the Alliance in achieving its goal of reducing rework in its projects.

Error culture measures were derived from Van Dyck et al. (2005) and based on the Error Orientation Questionnaire (EOQ) developed by Rybowiak et al. (1999). The EOQ scale comprised: (1) error competence; (2) learning from errors; (3) error risk-taking; (4) error strain; (5) error participation; and (6) covering up errors. Van Dyck et al. (2005) adapted the items of the EOQ "in such a way that they referred to common organisational practices and instructed participants to rate the extent to which each statement applied to the people in their organisation in general" (p.1231). A factor analysis was performed by Van Dyck et al. (2005) on these items to derive their overall measure of error culture.

The overall measure for error culture consists of two items (Table 1): (1) error management, which consisted of 17 items; and (2) error aversion, which consisted of 11 items, but we have added another five to reflect additional practices that have been observed in projects (Love and Matthews, 2020). The extra five items, numbers 12 to 16, can be seen in Table 2. Items were answered on a scale ranging from 1 (Does not apply at all) to 5 (Applies completely). The Cronbach alphas for both error items were 0.91 and 0.87, marginally more reliable than Van Dyck et al.'s (2005) scales.

In this research, we sought to determine if there was an agreement between subcontractors on the ratings of error culture and rework performance and goal achievement. We, therefore, computed the Intraclass Correlations (ICC) as estimates of interrater reliability to determine the consistency of ratings by ratees. A high degree of reliability was found for the error management and error aversion measures. The average measure ICC for error management was 0.90 with a 95% confidence

[3] Observations and conclusions drawn from a single case are cogent whenever it has some undeniable extraordinary aspect. Thus, Siggelkow (2007) draws on the metaphor of a 'speaking pig'. In this case, no reviewer can question the legitimacy of the case and comment: "Interesting, but that's just one pig. Show me a few more and then I might believe you" (p.20).

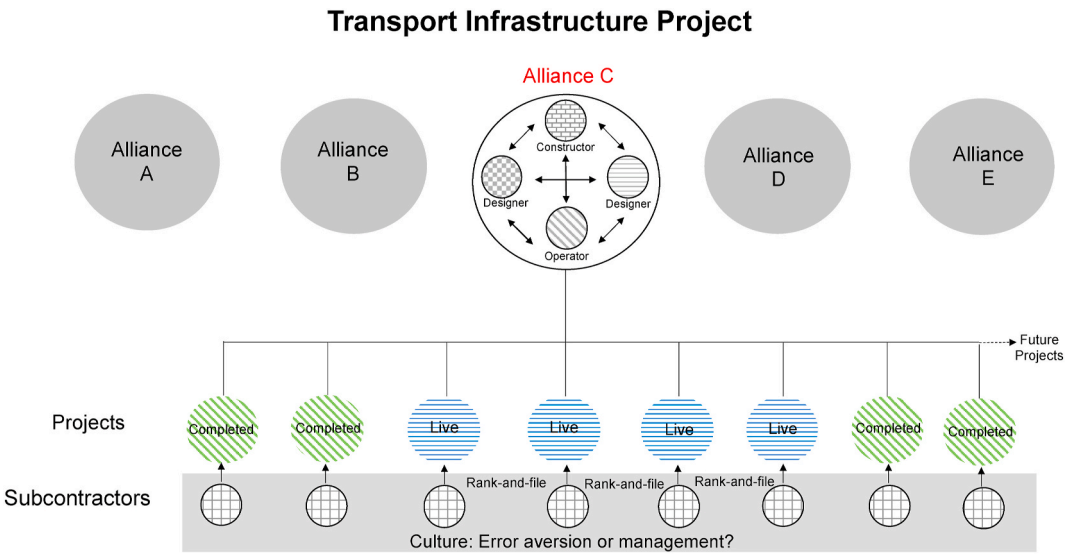

Fig. 2. The alliance and projects sampled.

Table 1
Project comparison for rework performance.

Rework Performance										
	Reduce rework after the IFC drawings		Rework due to design change requests		Rework due to non-conformances		Ability to reduce rework in comparison to other projects		Success is being able to reduce rework	
Location	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Project A	3.00	1.26	3.00	1.09	2.33	1.03	3.33	0.81	3.00	0.89
Project B	3.20	1.10	2.75	1.07	2.00	0.83	3.50	1.10	3.37	0.96
Project C	3.22	1.07	2.56	0.99	2.22	0.91	3.15	1.10	3.22	0.85
Project D	3.69	0.94	2.46	1.05	1.86	0.68	3.61	0.86	3.61	1.19
Other	2.66	0.57	3.00	1.00	2.66	1.15	3.00	1.00	2.66	0.57
Total	3.25	1.06	2.64	1.02	2.13	0.87	3.32	1.01	3.32	0.93

interval from 0.87 to 0.93 ($F(90,1440) = 11.66$, $p = 0.00$). Similarly for error aversion the ICC was 0.82 with a 95% confidence interval 0.75 to 0.88 ($F(90,1350) = 7.83$, $p = 0.00$).

4. Results

Of the 91 responses to the questionnaire survey, 48.9% were obtained from one project, as denoted in Fig. 3. Each of the projects is at a different phase of construction, and therefore the number of subcontractors on-site varies. Figs. 4–6 display the perceptions of rework performance, while Figs. 7 and 8 focus on the ability and success of the alliance to reduce the need for rework.

Respondents perceived work practices currently in place have been able to 'a large degree' reduce rework after the issue of IFC drawings. Design change requests and non-conformances were only deemed to result in rework 'to some degree'. So, we can see a combination of issues are contributing to rework, but for the rank-and-file workforce, non-conformances and having to attend to design changes appear to be issues that require attention.

However, it would appear that the Alliance has reduced its rework to lower levels than what respondents have experienced in other projects (Fig. 7). What is more, on the sites sampled, subcontractors suggest that the Alliance has been able, to a large degree, to reduce its rework, with almost 50% of respondents indicating this to be the case (Fig. 8).

A summary of the mean scores across the sampled projects for rework performance can be seen in Table 1. We applied a Kruskal-Wallis test (a non-parametric test also referred to as a one-way analysis of variance on ranks) to determine statistical differences between the variables in Table 1 across the four projects. No significant differences were found to be present ($p < 0.05$).

4.1. Error culture

The descriptive statistics for the error management and aversion items are presented in Table 2. As shown in Fig. 9, we also present a gap analysis between the mean scores for error management and error prevention. In general, we find that an error management culture largely prevails across the four sites of the Alliance, as evidenced in a rank-and-file workforce that learns from their mistakes, asks for help, and focuses on the goal when errors are made (Table 2). Contrastingly, issues associated with an error aversion culture appear not to apply at all or only to a minimal extent. There is, however, a tendency for the workforce to be apprehensive about making an error and possibly their ramifications (Table 2). Noteworthy, the workforce feels they are encouraged to report errors and believes that there is no merit in covering up errors should they occur.

In Table 3, we present the descriptive statistics and correlations of the study variables. We can see that error aversion culture is negatively related to error management ($r = -0.26$, $p < 0.01$). The result aligns with the findings of Van Dyck et al. (2005), though the correlation was not found to be significant in their study. Similarly, the correlation between error aversion and rework reduction was also significantly negative ($r = -0.26$, $p < 0.01$). Contrastingly, the correlation between error management and rework reduction is significantly positive ($r = 0.46$, $p < 0.05$).

5. Discussion

Our research demonstrates that the subcontractors' rank-and-file

Table 2
Descriptive statistics summary for error management and aversion scores.

Item	Error Management	Mean (N = 91)	Std. Deviation	Item	Error Aversion	Mean (N = 91)	Std. Deviation
1	For us, errors are very useful for improving the work process	3.10	1.12	1	In this Alliance/project, people feel stressed when making a mistake	2.79	1.15
2	After an error, people think through how to correct it.	3.90	1.03	2	In general, people in this alliance/project feel embarrassed after making a mistake	2.64	1.14
3	After an error has occurred, it is analysed thoroughly	3.81	1.14	3	People in this Alliance/project are often afraid of making mistakes	2.84	1.12
4	If something went wrong, people take the time to think it through	3.81	3.72	4	In this alliance/project, people are often upset and irritated if an error occurs	2.84	1.03
5	After making a mistake, people try to analyse what caused it	3.73	1.00	5	During their work, people are concerned that errors might occur	3.08	1.05
6	In this Alliance/project, people think a lot about how an error could have been avoided	3.67	1.07	6	Our motto within the Alliance/project is, "Why admit an error when no one will find out?"	1.45	0.83
7	An error provides important information for the continuation of the work	3.37	1.27	7	There is no point in discussing errors with others	1.61	0.99
8	Our errors point us to what we can improve	3.38	0.98	8	There are advantages in covering up one's errors	1.40	0.80
9	When mastering a task, people can learn a lot from their mistakes	4.01	0.96	9	People prefer to keep errors to themselves	2.18	1.10
10	When an error has occurred, we usually know how to rectify it	3.80	0.85	10	Employees who admit to errors are asking for trouble	1.60	0.95
11	When an error is made, it is corrected right away	3.78	0.88	11	It can be harmful to people to admit their errors to others	1.82	1.04
12	Although we make mistakes, we don't let go of the final goal	4.03	0.96	12	In this Alliance/project, we don't talk about errors	1.61	0.96
13	When people are unable to correct an error by themselves, they turn to their colleagues	3.82	0.95	13	In this Alliance/project, we have a zero- vision in place for errors	2.16	1.13
14	If people are unable to continue their work after an error, they can rely on others	3.59	1.08	14	When errors occur, it takes time before they are rectified	2.83	0.96
15	When people make an error, they can ask others for advice on how to continue	4.00	0.87	15	People are discouraged from reporting errors	1.68	1.00
16	When someone makes an error, they share it with others so that they don't make the same mistake	3.72	1.04	16	It is difficult to ask other people for help to address a mistake	1.87	0.94
17	In this Alliance/project, people think a lot about how an error could have been avoided	3.71	0.95				

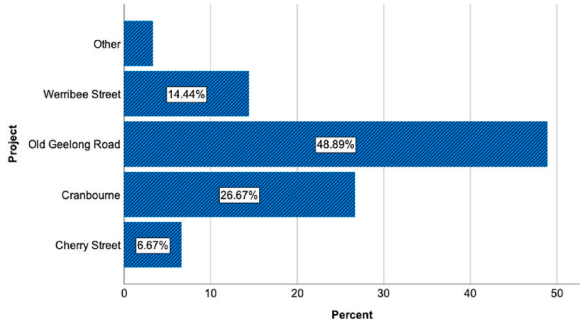

Fig. 3. Responses by project.

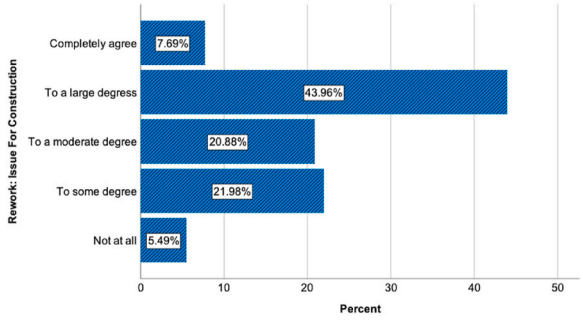

Fig. 4. Reduce rework after the IFC drawings.

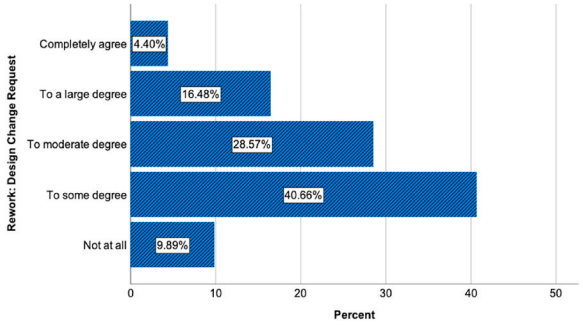

Fig. 5. Rework due to design change requests.

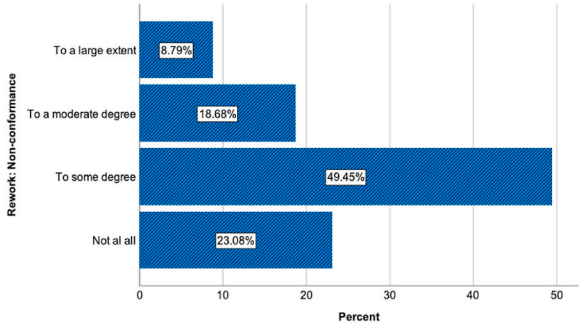

Fig. 6. Rework due to non-conformances.

workforce perceived that the Alliance's error management positively reduces rework within its projects. Reduced rework will minimise associated wastes (e.g., transportation, stoppages, waiting and motion) and improve productivity and safety (Love et al., 2018a). In the study undertaken by Van Dyck et al. (2005), an error management culture

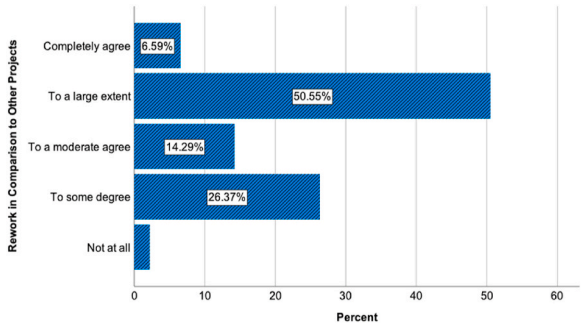

Fig. 7. Alliance's ability to reduce rework in comparison to other projects.

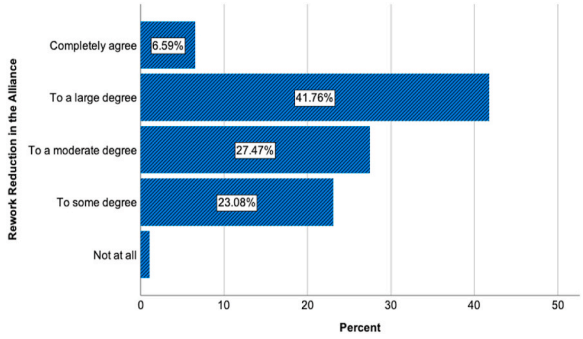

Fig. 8. Alliance's success in being able to reduce rework.

positively affected a firm's performance while reporting a M = 3.43, SD = 0.41 for their sample. Our case's measure for error management culture is marginally higher (M = 3.75, SD = 0.94) than reported in Van Dyck et al.'s (2005) study. Thus, we can conclude that error management positively impacts the alliance's subcontractors' rank-and-file workforce's ability to reduce rework.

To reiterate, studies that have sought to quantify rework have only accounted for a proportion of the total that arises during construction as definitions used for its quantification vary. Knowledge about the actual costs of rework remains primarily unknown, particularly those of an indirect nature (Love and Smith, 2019). However, we know that if we reduce rework, safety improves (Wanberg et al., 2013; Love et al., 2018c). Errors are contributors to poor quality and safety incidents. Thus, construction organisations can improve their performance and productivity by engendering and enacting an error management culture.

Culture holds an organisation together and motivates people as it provides the values, mindsets and sets a standard of behaviour. An adaptive error culture, such as error management, is critical for containing and reducing errors that can result in rework being needed. Yet little is known about error culture in construction, but it has naturally materialised in the Alliance's case. The Alliance's underlying philosophy and principles have transcended to the sharp-end of construction, enabling the rank-and-file workforce to feel comfortable handling errors and the rework that materialises. Notably, many subcontractors have worked with the Alliance on previous works and are employed on several current projects. Informal discussions with a subcontractor indicated that the continuity of work provides the basis for trust to be established and enable 'open and robust communication' on site.

Maintaining and sustaining an error culture can be challenging as it requires people to alter their habitual behaviours, which are naturally aligned with error aversion. For example, some respondents perceived that, to some degree, 'people prefer to keep errors to themselves' and 'people are embarrassed about making mistakes.' Indeed, these are natural reactions to errors, but through fostering and reinforcing psychological safety amongst the rank-and-file workforce by the Alliance's site management team, error-making becomes an accepted feature of practice. Furthermore, by actively engaging with subcontractors, listening and understanding their problems, excluding negativity, including them in the decision-making/problem-solving process and being open to feedback, site management will create a psychologically safe workplace in their projects.

Table 3
Descriptive statistics and correlations between variables.

Variable	Mean	SD	Rework Reduction	Error Management	Error Aversion
1. Rework Reduction	3.29	0.93			
2. Error Management	3.75	0.66	**0.34**[b]		
3. Error Aversion	2.15	0.59	**-0.26**[b]	**-0.26**[a]	-

[a] Correlation is significant at the 0.05 level (2-tailed).
[b] Correlation is significant at the 0.01 level (2-tailed).

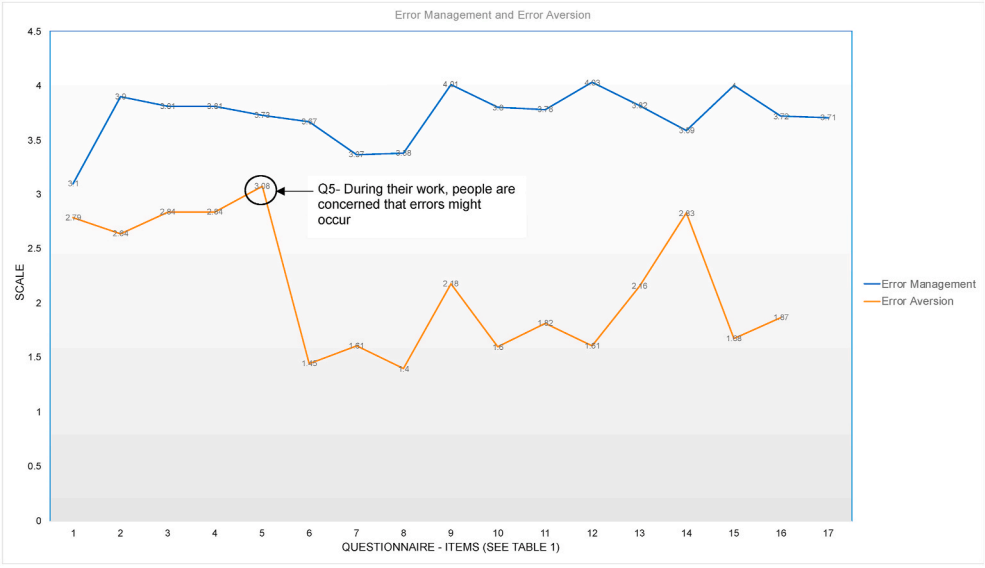

Fig. 9. Gap analysis between error management and error aversion.

There is no silver bullet that can reduce rework – it is a *wicked* problem (Love and Smith, 2019). But, having an organisation structure, decision rights systems, measures, and incentives to help drive an error management culture provide the foundations to tackle this problem. If errors are to be responded to quickly, then a minimal management layer needs to be in place to ensure information is not filtered out—the flow of information influences cooperation and the functioning of an organisation (Westrum, 2014). A 'gain-share/pain-share' regime exists as an incentive within an Alliance contract. Be as it may, incentives are eschewed within the back-to-back contract between the Alliance and their subcontractors. By incentivising subcontractors in a similar vein, particularly within the context of quality, rework incidence may reduce further. However, this would not necessarily be the case for rework initiated by design-changes. Still, subcontractors' input to jointly solve problems caused by errors or omissions in drawings and documentation would undoubtedly be invaluable.

During construction, lean tools such as the Last Planner® enable Supervisors or Superintendents to collaboratively engage with those who execute the work to plan, identify and remove constraints as a team. As a result, the Last Planner® is widely used in the Alliance. While we have not sought to determine its effectiveness in reducing rework, previous research indicates that it plays an invaluable role in improving workflows, relationships, continuous improvement and learning (e.g., Ballard and Howell, 1998; Lerche et al., 2020). To this end, Last Planner® provides site management and subcontractors with the ability to detect, adapt and respond quickly respond to errors, omissions, and changes to design and thus mitigate the likelihood of rework.

Communication about errors is the most critical error management practice (Van Dyck et al., 2005). A high degree of communication about errors enables the development of shared knowledge. When people can openly discuss errors and rework, as they can do within an error management culture, a mutual understanding of high-risk situations (i.e., error traps) and error handling strategies will emanate (Mathieu et al., 2000). For example, the Barwon Water Alliance (BWA), which delivered 129 water infrastructure projects over five years, held regular forums with their subcontractors to share their knowledge and experiences and knowledge with rework and discuss ways to handle its occurrence (Love et al., 2021a). Regular knowledge sharing forums with subcontractors can result in the emergence of coopetition and situated learning and the reduction and containment of errors (Love et al., 2015).

Having a *Maestro* that can lead and maintain a questioning attitude during such forums is needed to stimulate reflexive practice. Adamski and Westrum (2003) cogently suggest that people should have a "restless mind" so that lessons can be learned and implemented in the future (p.217). Thus, during pre-starts, for example, the Supervisor/Superintendent could assume the role of a Maestro and juxtaposed with the subcontractor's rank-and-file workforce frame a series of questions around 'What situations have not been foreseen?', 'What has been forgotten?', and 'What could go wrong?' (Love and Matthews, 2020). Working together to understand and anticipate 'what might go wrong' helps with the creation of collective mindfulness[4] enabling the project team to operate reliably and effectively when they confront complex challenges and conditions (Weick et al., 1999) or what Bennett and Lemoine (2014) refer to as 'VUCA' – volatility, uncertainty, complexity and ambiguity. When an alliance team collaborates with its subcontractors, they learn together, and performance and productivity can significantly improve (Love et al., 2021a).

5.1. Limitations

While this research is exploratory and the first to examine a subcontractor's rank-and-file workforce perceptions of a project's error culture, it is not without its limitations. In addition to the limited sample, we have mentioned earlier, the absence of quantitative rework data resulted in perceptions (i.e., what respondents believe, think and feel) only being measured. Thus, accessibility, reliability, and representativeness immediately come to the fore and must be considered. Almost half of the respondents answering the survey originated from one project. Though respondents ' ratings were consistent, social desirability[5] bias may also have been presented. Within construction, low-levels of literacy and low English proficiency are common amongst the rank-and-file workforce, which may have also prevented respondents from completing the survey (Lin et al., 2018; King et al., 2019). Finally, we have only focused on error culture and its influence on rework. Thus, we have not considered mediators such as leadership, psychological safety, learning and secondary error prevention mechanisms.

5.2. Contribution and implications for future research

Irrespective of the limitations we have outlined above, the research has determined the existing homogenous error culture present at the sharp-end of construction. Therefore, our research question sets out to determine the type of error culture that subcontractors rank-and-file workforce experience in an Alliance and its contribution to mitigating rework. Using a well-established measure of error culture, we found that error management had a positive association with reducing rework. Thus, our exploratory is the first of its kind to show that an error management culture experienced at the sharp-end of construction can result in reductions in rework.

We added items to the error aversion scale developed by Van Dyck et al. (2005), and its reliability improved, though marginally. We were also able to demonstrate a significant negative correlation between error management and error aversion (i.e., show their divergence), which previous studies have not been able to do, even though they are contradictory constructs (Van Dyck et al., 2005). Considering this important finding, we question whether error management should be regarded as an "add-on" and create an adaptive culture (Frese, 1991: p.776; Frese and Keith, 2015). The research by Dimitrova et al. (2017) reinforces our questioning here as "error prevention and error management have unique outcomes on negative effect, self-efficacy, cognition and performance" (p.658), which will influence the ability to contain and reduce errors and rework.

Our exploratory line of inquiry has provided the initial platform to examine error culture and its influence on rework in construction. Agreeably, more work should be undertaken to understand better the dynamics of error culture and mediators' impact on rework. Additionally, we should not ignore violations as they can also require rework (Love et al., 2009). As noted by Frese and Keith (2015), error prevention, error management, violation prevention and violation management "should be examined with the same studies to explicate their interrelationships and differential effects" (p.682). However, the challenge is obtaining access to data and determining its format, as construction organisations often do not acknowledge errors and their contribution to rework. Needless to say, we suggest that future research should strive to ensure methodological pluralism through triangulation, whereby qualitative and quantitative data can be used to maximise validity and reliability. In this instance, case studies effectively ensure the homogeneity of a project's error culture is guaranteed.

[4] Collective (or organisational) mindfulness is a social phenomenon and refers to a state of shared awareness and attention that emerges from interactions between multiple actors, "a totality with intricately connected and interdependent components, from which organisational mindfulness emerges at the system level." (Carlo et al., 2012: p.1102).

[5] Social-desirability bias is a type of response bias where there is a tendency for respondents of a survey to answer questions in a manner that will be viewed favourably by others (Krumpal, 2013).

6. Conclusion

Research examining the error culture in construction has been limited, specifically its influence on rework. Despite the negative impact of rework on organisational and project performance, many construction organisations have been unenthusiastic about addressing this insidious problem even though it is a *zemblanity* (i.e., an unpleasant, yet unsurprising discovery). In addition, construction organisations lack systems and processes that can capture and quantify rework, which has somewhat contributed to a lack of appetite to address this problem.

Recognising that rework can adversely impact safety and productivity, the Alliance, which forms part of a transport mega-project, in conjunction with the authors, undertook an exploratory study to determine the error culture that prevailed in its projects and, in doing so, solicited the views of its subcontractors' rank-and-file workforce. The measures of error culture developed by Van Dyck et al. (2005) were used to create a questionnaire survey to assess their influence on rework in four of the Alliance's projects. We received 91 valid responses, which were subsequently analysed. An error management culture was found to contribute to reducing rework significantly. However, we also demonstrated a significant negative correlation between error management and error aversion. Consequently, we question whether error prevention should be combined with error management, within the context of Alliancing or variants thereof such as Integrated Project Delivery, to create an adaptive culture that minimises the negative and maximises positive error consequences.

Our exploratory study has laid the foundation for further work on error culture and how training in error management can lead to better learning and reduced rework in transport infrastructure projects delivered using Alliances. We also believe this exploratory work will provide an impetus for creating a new line of inquiry into the relationship between quality and safety, considering their symbiotic relationship. Future research is required to examine error culture to a broader range of construction projects and its ability to help mitigate rework.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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