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Understanding and Learning from Failure

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Understanding and Learning from Failure

Abstract

Failure is an intrinsic part of systems, including construction. While there is a less than consistent understanding of what failure is, it is an aspect of human nature that we wish to learn from mistakes. To gain insights into how failure is understood and what failure means in construction, and as a precursor to developing learning materials for higher education students, the outcomes of 19 semi-structured interviews with construction personnel in the UK are presented. The interviews explore processes employed by the construction industry to capture, understand and extract learning from these events, including an exploration of any perceived attitudes towards failure, and whether such attitudes are barriers or aids to effective learning in practice. Findings revealed different types of failure within the construction industry, manifested as separate and individually developed learning cycles, while attitudes towards failure impact the learning process. Two pairs of attitude stimuli were revealed: Ownership and Blame; Acceptance and Leadership. These findings are then used to provide learning tools for undergraduate students in built environment degree programmes. A taxonomy of failure was developed, incorporating three levels of causes, symptoms and consequences. A face validity exercise with industry experts provides the confidence to adopt this taxonomic approach.

Keywords: Failure; education and training; UN SDG 9; taxonomy; interview

Introduction

> "No one *wants* to learn by mistakes, but we cannot learn enough from successes to go beyond the state of the art".
>
> *Petroski, 1985*

This quote from Henry Petroski's *To Engineer Is Human* (1985: 62), with Petroski's emphasis on the third word, is as applicable in the construction industry today as it was nearly 40 years ago. Petroski believes that learning from success only is not enough and while his thesis of learning from failure is almost universally exhorted as a 'good idea', with Love et al (2008) identifying 'lessons learned' initiatives as being widespread, Cannon and Edmondson (2005) note that the practice of implementing systematic learning from failure within organisations is something that most find easier to espouse than to effect.

On an instinctive level, learning from past experiences should be natural. This type of *experiential* learning is observed throughout the learning cycle of children and adults alike and, as Kolb (2015) notes, is defined as *lessons extracted from the ordinary course of life*. However, converting this learning to an organisation or industry is notoriously difficult and learning has been historically limited to large public engineering system failures, such as that of the Tacoma Narrows Bridge (1940), the Hyatt Regency Hotel walkway (1981) or more recently the Grenfell Tower fire (2017). This difficulty can be attributed to a combination of the technical complexity with implementing continuous learning in an organisational context, coupled with negative social and psychological reactions that most people exhibit when faced with the reality of failure (Cannon and Edmondson 2005).

Evidence of the difficulties of learning from failure, even large failures, can be observed in the recurrence of similar failure types, which is before the issues of generational forgetfulness (see Hewlett, 2019) are even considered.

By developing a deep understanding of established learning processes and attitudes towards learning from failure, the construction industry can begin to pick apart individual barriers and address them to facilitate learning on both individual and organisational levels. The research presented here explores this fundamental necessity, using in-depth semi-structured interviews with members of the construction industry to understand the different processes currently employed to feedback learning from failure, and to investigate the perceived attitudes towards learning from failure. This understanding is then used to provide a taxonomy of failure as a means to develop learning materials aimed at built-environment degree students. We shall provide a contextual understanding of the literature of failure, followed by an overview of the interview process and its raw data analysis. The findings from this thematic analysis will be discussed and followed by a presentation of a failure taxonomy model.

The contribution of this work is two-fold. First, by gaining first-hand accounts of the perceptions and narratives of failure from industry professionals we hope to further the discourse around failure, allowing industry to lessen the taboo of failure and accept ownership. We also hope to help in the seed-sowing of wider attitude shift by exposing undergraduate students to these concepts, allowing them to learn how to *fail better*, and take these understandings with them into built environment careers.

The context of learning from failure

Do we ever learn?

In 2014, Drupsteen and Guldenmund undertook a systematic review of 47 separate studies that considered organisational learning through the lens of Argyris and Schön's (1996) models of learning cycles. That framing of organisational learning in a safety context will be considered in more detail shortly, yet one of the most striking conclusions was simply that while there are large numbers of research studies, most are theoretical with too few examples of how incidents are actually used to learn from. More recently in 2018, Stemn et al. also reported limited implementation of learning from failure within industry, specifically considering failure as *undesirable or unintended outcomes*.

Successful examples of such learning rely on individuals identifying what they believe to be significant cases of failure on their project, either for their general applicability or potential consequences, and then disseminating this information to a wider audience. Communication of this failure may then take place in a number of ways. On a day to day basis this can be in the form of an alert or storytelling, either to an individual, via IT or verbally. Much more systematic are forums such as CROSS[1] set up to disseminate to industry early warnings of failures that could become more common if not addressed (see Soane 2015).

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[1] CROSS is now known as *Collaborative Reporting for Safer Structures*, though previously was *Confidential Reporting on Structural Safety* as the data collection part of the *Standing Committee on Structural Safety,* an organisation jointly established by in the United Kingdom by the Presidents of the Institution of Structural Engineers (IStructE), the Institution of Civil Engineers (ICE) and the Institution of Municipal Engineers (IMunE).

Silva and Lima (2005) also identified two further intervention strategies used to implement learning, in addition to *diffusion* and *discussion* highlighted above. *Training* refers to the use of incident information to improve or introduce employees' training, while *change* describes the adjustment of a procedure or standard in response to an incident. These are both top-down approaches instigated by leadership.

From information aggregated by Drupsteen and Guldenmund (2014), a generic *stepwise learning* cycle can be defined. This typical single-loop learning cycle is identical to the one described by Argyris and Schön (1996). It focuses on correction of procedure or actions to prevent recurrence but does not examine the underlying values. Argyris and Schön use the example of adjusting the temperature instruction given to a thermostat to correct the failing of a cold room. The instruction is corrected to prevent failure; however, the values and culture behind the process are not questioned, e.g. they did not ask if donning a jacket would achieve the same job more efficiently. If this extra loop is included, Argyris and Schön refer to this as double-loop learning. Double-loop learning is often considered a superior method; with Stemn et al. (2018) suggesting that classification of whether an implemented learning system included and/or encouraged double-loop learning could help define the effectiveness and maturity of the cycle.

What is failure anyway?

There is also a lack of agreement in literature regarding what constitutes failure. Defining it is often a complicated task (Wantanakorn et al., 1999), with some psychologists claiming that errors are a cognitive product of a person's abilities and do not actually exist (Reason and Hobbs, 2003). Failure is also often referred to in terms such as 'error', 'mistake' or 'incident', making it increasingly hard to define and understand it. Therefore, there is a need in the industry for a clear appreciation of the complexity of failure as a phenomenon that cannot be defined simply and requires a novel representation.

Most of the research done on failure is from a reactive stance. Using backward analysis, authors have claimed that errors may stem from design (Lopez et al., 2010), failure to learn (Sage et al., 2014), and lack of adequate health and safety measures (Hinze and Pedersen, 1998). Methods for dealing with failure in the construction industry can also be reactive. For instance, the Root Cause Analysis method was developed as a way to identify the factors that resulted in the harmful outcome of a past event.

More recently, systems engineers have used more active approaches for risk identification and failure prevention. Bow-tie analysis is a risk evaluation method for exploration of the causal relationships in a risk situation. Besides presenting a visual summary of potential accident scenarios for a given hazard, it showcases control measures for controlling and preventing failure (Ferdous et al, 2013). Without explicitly naming it, the method recognises a three- (or five) level relationship: threat- (control measure) - failure - (remedial) - consequence.

The Swiss Cheese model proposed by Reason in 1990 relates to the controls in the bowtie method. According to this metaphor, each level of control has weaknesses, or 'holes', which on a single level are harmless. However, when several holes from different levels align, a hazard can occur, causing failure of the system. Reason (1990) argued that holes are due to a combination of active failures and latent conditions. While active failures such as slips, mistakes and lapses occur due to 'unsafe acts', they are underlain by the invisible latent conditions of the organisation.

Can failure be classified?

While these models attempt to predict failure and prevent it, they do not actually classify it despite using categories such as ‘threats’ and ‘consequences’. Failure is a multi-faceted phenomenon, unlikely to be described accurately by a single-level definition. Instead, taxonomy can be used to define failure and to demonstrate the intricate relationships between the different levels of failure. Taxonomy, originally used to classify biological organisms into groups of similar origin, has become an increasingly useful approach to classify concepts and explain the relationships between them (Boulding and Khalil, 2002).

Instead of forming a vocabulary, which would not be able to showcase the causes of failure, taxonomy presents an innovative way to examine it. Taxonomy has previously been used to aid understanding of complex systems, primarily in the field of aviation. O'Hare (2000) developed a taxonomic approach to accident investigation, and represented it in his 'Wheel of Misfortune', which summarises the outcomes of many accident investigations. The usefulness of such classification has been recognised and adopted by the New Zealand Civil Aviation Authority as part of their accident analysis system. A similar methodology to the one employed in this research was used by Plant and Stanton (2017), who developed a 28-item taxonomy to describe decision-making in critical aeronautical situations. Their research focuses on understanding systems failure both in terms of structural and human error, and has a potential to improve the aviation industry in a similar manner that this research aims to improve the construction industry.

Our conclusion from this brief review is that there is an inconsistent and limited approach to understanding of and learning from failure in the construction industry, potentially exacerbated through variable attitudes to what failure is in the first place. The inconsistent way in which failure itself is defined suggests that a taxonomy of failure could be used to aid in its understanding, which in turn can be helpful in preventing it. These conclusions prompt us to pose three research questions in an attempt to further this investigation:

1. What systematic processes for learning from failure exist in the construction industry?
2. Are there identifiable attitudes surrounding learning from failure?
3. What could a taxonomy of failure for the construction industry look like?

Research approach

To investigate these questions an in-depth examination of the features of both failure itself and the learning processes from failure is needed, alongside associated attitudes that might be present. To this end 19 semi-structured interviews were conducted with members of the UK construction industry across several infrastructure sectors at different levels of business. Semi-structured interviews allow a fluid format to the discussions, including clarifying questions while ensuring the relevant topic areas are covered (Harreveld et al 2016). The interviewees were approached through mutual professional acquaintances and Table 1 shows a demographic summary of the interviewees.

Taking guidance from Silverman (2013) the role of the researcher is often discussed in relation to his or her impact on the research being carried out, and this is especially important in qualitative research. Therefore, in designing the research and interview prompts, neutral language was aimed at to avoid bias or leading questions. Having identified prior to the interviews that asking about failure in relation to blame or avoidance would be problematic, the prompt for this drew from the work by Nikolova et al (2014) which explored 'error avoidance learning climate' as part of a quantitative piece on measuring workplace learning climates. A downside is that the interviewers' preconception of what is and isn't important or relevant may encourage the conversation on certain routes of enquiry and possibly neglected others. In order to mitigate unconscious bias in this area, close examination of the literature was withheld until after completion of the interviews themselves, though it is accepted that it is impossible to eliminate bias from any interview situation. The outcomes must therefore be accepted as being derived from an interpretivist rather than positivistic standpoint.

Table 1 appears here

Data were acquired from the interviews in the form of both interview notes and transcripts, which were typed verbatim but did not include indication of pauses and intonations. Thematic analysis (Silverman 2013) is a standard method used by social scientists for qualitative research and is an iterative method used to draw out underlying themes. When properly implemented, it can be powerful at identifying key factors within context, and correlations which aid the formation of insights and conclusions. It should be noted that analysis in this way cannot prove causality, which would be better shown in a more experimental or action research method. For the research questions posited here, namely what processes and attitudes exist and identifying suspected interplay, thematic analysis is appropriate.

This analysis was based on the approach outlined by Braun and Clarke (2006) using spatial prevalence to identify themes. Similar to considerations in conducting the interviews themselves, the active position of the researcher who determines the 'themes' in thematic analysis is undeniable and must be acknowledged. A qualitative data analysis software – Nvivo Version 12, (QSR International Pty Ltd., 2018) - was used to code the data set.

The key processes and attitudes revealed by this analysis will be explored next. Identified themes were transitioned into a taxonomy and then into a tool, described later in this paper.

The Narrative and Discussion

Process Identification

To open the discussion, interviewees were asked what would constitute a failure either to them or their colleagues at work and how this would then be dealt with. This resulted in the identification of several project 'failure modes' which form the inputs to the learning process. Three core modes, consistently identified in discussion were: time, money and health & safety. Other commonly cited failure modes, such as quality and problems with setting out requirements, were sub-categories of these – as one interviewee said, 'the others all feed into these three'. A further mode, identified by two separate interviewees, which does not directly feed to one of the 'top' three is 'public perception'. These identified failure modes are all well documented consequences of risk in engineering project management (see for instance Munier, 2014).

For each of these failure modes, it became clear that there were defined stages of learning from an individual failure which matched the generic *stepwise learning* cycle set out by Drupsteen and Guldenmund (2014). This single-loop learning cycle was characterised by an initial information gathering phase following an incident followed by a period of initial remedial action and alerts. Some of these incidents then progressed to a long-term change or formal learning implementation.

Additionally, while the different learning processes identified in this analysis were consistent across different companies and engineering specialities, the maturity of some aspects varied depending on sector. For example, Interviewee 2 noted that working in rail, he expected engagement with reporting Non-Conformance Reports (NCRs) to be less than the nuclear industry, but ahead of general building construction. This should not be surprising, and is consistent with previous findings (Carter and Smith, 2006) that demonstrated variable attitudes in these different sectors.

Safety

Safety was the most mentioned failure with all the interviewees, with a notable exception of the two client representatives, stating that it was a potential form of failure within the industry. Moreover, 12 of the 19 interviewees identified H&S failures, such as incidents involving injury, as the focal form of failure in the construction industry. Of the identified failure modes, interviewees recognised safety as mature in respect to the paperwork and formal process. One interviewee stated that:

> *Safety legislation is there, […] I think for me dealing with safety and minimising failure, it's a state of mind and it's a culture*

This was reinforced by other interviewees who were pleased by the current system and referred to the process as *industry standard*, although several acknowledged that there were still steps to be made to improve the uptake and personal buy-in of certain learning stages. Additionally, there is a wide belief that more needs to be done to drive these processes down to contractors and the rest of the supply chain.

Overall, the safety learning cycle was presented as a closed, well-standardised single-loop learning cycle where information is collected, analysed, distributed and then stored. However, questions can be raised over which information is collected. Interviewees tended to be content with this learning cycle for larger incidents but considered that it was insufficient for smaller events, considering the potential self-imposed perception of what was important to be a weak link in the learning cycle. For example, a small incident might not be recorded or it would prove too costly in terms of time and/or resources to investigate it. In the UK this may also stem from the presence of RIDDOR – Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (HSE, 2013) which implies non serious incidents, principally those which result in less than three days of a worker being away from work, do not need to be recorded. In terms of the nature of the actual learning that takes place, even when full RIDDOR compliance is being observed, as pointed out by Duryan et al (2020) the question remains as to whether reporting involves learning as well.

Behavioural science or developing a *positive safety culture* was mentioned explicitly by 7/19 interviewees. The inclusion of values and culture into the learning cycle marks the migration from single-loop to double-loop learning. This type of learning could tackle underlying issues which are currently inhibiting learning. It is not without negative consequences, though, with Bye et al. (2015) for instance noting that the attention given to culture could be a 'two-edged sword' as the use of 'poor safety culture' as a reason for incidents might lead to premature closure of an investigation into root causes, which are key to efficiently reducing recurring failures (Haslam et al. 2005).

Quality

Non-compliance or poor build quality was identified by half the interviewees as a specific failure. While the initial learning process presented by interviewees is extremely similar to that in place for H&S, there were more concerns over under-reporting, lack of analysis and inadequate feedback. Several interviewees were keen to point out that there were systematic quality checks in place to avoid non-compliance reports (NCRs) including managerial reviews required by ISO 9001. Interviewee 10 stated

> *Generally, quality is quite well-managed, we use quite tight process to ensure we use the correct products and the correct stuff and that it’s all approved.*

However, this active management generally refers to managing quality prior to failures or implementing remedial action to ensure the quality of the end-product, not implementing systematic learning from failure. The majority of interviewees were pleased with the level of immediate response of an investigation and remedial action; nevertheless, they found that long-term trends and learning opportunities got lost in the *blame game*. The general message was that NCRs were used actively on projects for *firefighting* and remedial action; however, there was far less engagement with analysis than seen with H&S. Interviewee 1, a technical director, stated that they *probably do nothing* with the reports, acknowledging that there *should be some kind of statistical analysis* to identify trends similar to H&S data.

Reporting engineering non-compliance (NCRs) was referred to as *a little bit scary* and it was indicated several times that people were more willing to submit snag or improvement reports as the personal consequences were seen as less severe. The exception to this rule was when there were accompanying potential safety consequences that were judged to be *serious* or *life-threatening*. Discussion of new technology for reporting presented an interesting conflicting view where a younger interviewee remarked that it made reporting quicker and easier to store, while an older interviewee stated that it made reporting more opaque and less accessible to those on site.

A conclusion could therefore be that quality has a far less complete single-loop learning cycle as safety. While information is captured, very little analysis and extremely sparse distribution occurs. Equally, while the information is generally electronically stored, this tends to be silo-ed by project, rather than in a central data repository, and access is limited both by permissions and opaque search tools. Nevertheless, it should be noted that interviewees gave good examples of informal feedback and team discussion to analyse or learn from serious examples of these events. These unformatted *lessons learnt* exercises were occasionally captured for future learning, but interviewees were often sceptical as to their worth.

Time and Money

Time and money were also identified as key factors in defining project failure; however, learning from incidents of overrun or exceeding budget were less well defined and varied greatly between levels of the business. These failure modes refer to more commercially sensitive root causes and are not as easily captured.

Tacit learning was, therefore, the only identified method of on-the-job learning along with some mention of generic formal training courses. Consequently, innovations within this section of business are kept within a very small community. Executive groups or small communities tend to share their internal learning using *discussion* such as informal *lessons learnt* sessions. Interviewees working in these areas did not feel it inhibited their individual learning on projects as the teams are small; however, they acknowledged that staff turnover and lack of formal capture restricted learning outside each project.

While accounting records and schedules should record changes and why these events occurred, there is no systematic cyclic assessment and feedback/distribution of information within (or outside) the business. Although 'notice to delay' exists, its use is misconstrued and therefore not used properly. The lack of systems approach for cost overrun has been explored by Ahiaga-Dagbui et al. (2016), however no robust methods have been suggested for improving capture and analysis of this failure type.

Attitudes to Failure

While failure as a whole could be taken as the input here, there are several separate issues that stem from failure which were found to drive certain behavioural responses. These are subsequently referred to as *attitude stimuli*. During analysis of the interview data, key attitude stimuli were identified with their corresponding responses. Two pairs of these stimuli will be discussed here: ownership and blame; and leadership and acceptance.

Ownership and Blame

A theme which emerged was reluctance to take ownership of the failure. Multiple interviewees alluded to this with a few citing reasons such as: *not good for your CV*, *if I knew my job wasn't on the line* and *it's very painful, it's embarrassing*. One interviewee pointed out that directly employed members of staff or those employed by the main contractor were more likely to raise an issue because, as they put it, *they feel ownership because they are part of a larger group*. There was also mention that by specifically referring to job security and the length of work during inductions, the site workers tended to be more involved in the job, rather than just carrying out the assigned task. This concurs with recent emphasis in research, such as Sanne (2008), on increasing employee ownership to cultivate a productive reporting procedure.

On the other hand, for failures where there existed an overwhelming sense of moral obligation to take ownership, interviewees expressed increased satisfaction with the learning process. For example, not only do H&S failures have a legislative motivation for control, there is also a moral imperative to help preserve life and quality of life to others. This was expressed by one interviewee succinctly:

Everyone is very open-minded about sharing lessons learnt from safety incidents because of the overarching moral obligations.

Perhaps due to the varying degrees of perceived moral obligation, different failure modes seemed to elicit different levels of personal or company ownership. In comparison to H&S as already outlined, discussion on quality failures led more to blame and legal consequences, for example contractual conflicts. Additionally, if quality processes can be improved by a certain action, it is in the interest of the company to keep it undisclosed as a Unique Selling Point. Such reasoning overlooks the interdependent nature of quality and safety in construction where investigations have indicated mutual causality, where each performance type positively impacts the other (Wanberg et al. 2013, Love et al. 2015). Given this, the industry should ask itself, "is it morally justified to keep back significant quality information?"

Reluctance to take ownership had significant co-occurrence with the theme of personal blame or consequences. Some of the many quotes on the subject were:

> *“We live in a world of blame culture. Whether you like it or not.”*
> *“People always worried about being the one at fault.”*
> *“You got your battle lines drawn very quickly.”*

This discourse of blame and fault is at odds with recent research and policy to foster a no-blame culture, especially within H&S, to not only address learning but also encourage collaboration and innovation (see, for example, Lloyd-Walker et al. 2014).

An interesting finding was the role interviewees perceived the UK's Health and Safety Executive (HSE) takes in regard to H&S learning within industry. Several times it was hinted that inclusion of an independent body within the learning cycle shifted the internal focus from blame and personal culpability to learning and fair distribution of information. The legal obligations also gave professionals within the H&S industry an external scapegoat to avoid internal conflict as Interviewee 7, a H&S advisor, noted he was able to say to site staff in relation to enforcing H&S that *it's not just me once or twice a month, HSE could come up here any time*.

Acceptance and Leadership

Acceptance of failure, or rather the lack thereof, emerged as an important attitude stimulus within the discussions with interviewees.

> *They go: […] "It will never happen to me".*
>
> *People […] think "oh, we'd never do that on our project".*
>
> *I wouldn't say we had any failures*.

This topic co-occurred with discussion of the role of leadership and top-down incentives for encouraging learning from failure. It was explicitly stated that increasing incentives and the acceptance of failure will aid prevention of failure:

> *I think people should be incentivised to produce these things and to accept the fact that we've got something wrong. Because, if you don't accept the fact that you've got something wrong, you're never going to prevent those things happening.*

It was indicated by several interviewees that learning from failure is not incentivised. Several interviewees noted that leadership are often given financial incentives for productivity or profit which is in direct conflict with the acceptance of failure. On a personal level, one interviewee noted that a project which was considered a failure is bad on your job record. However, projects are an amalgamation of the work and effort of a (sometimes huge) number of people and the overall success or failure of a project rarely reflects on the specific value an individual brings to the job or the valuable learning gained from this. This observation can also be scaled up to the company as, when bidding for work, successes are emphasised, and failures unheeded. One interviewee explained the situation succinctly:

When you tender for work, clients will ask you what you got right, never ask you what you got wrong and what you learn from it. [...] I find that's an interesting way of just ignoring it basically.

A taxonomy of failure

The thematic analysis of interviews discussed above revealed that participants recognised the existence of causal relationships in failure. The most commonly mentioned 'failures' were then, subsequently, classified as either causes, symptoms or consequences, which became the basis for a three-tiered failure taxonomy. This taxonomy is part of the failure lifecycle, presented in Figure 1

Figure 1 appears here

In the failure taxonomy, ***causes*** are factors which have the potential to result in a failure. Examples provided by participants were *poor communication*, *inexperience*, *lack of clarity about the project scope* etc.

The second level- ***failure symptoms*** - are processes that can be immediately observed. For instance, participants mentioned incurring *unexpected costs* or *time overrun* as symptoms of failure.

The third level of the failure taxonomy refers to ***consequences***. These are long-term actions that may not be immediately visible. They could be tangible (like *loss of profit*), or intangible, such as *loss of reputation*.

To address the third of our research questions – “What could a taxonomy of failure look like?” the relationships between these three tiers of the taxonomy were examined. The thematic analysis, discussed previously, revealed that research participants recognised 11 common causes of failure, 12 symptoms and 6 long-term consequences. However, it was clear that interviewees did not always recognise nuances in the levels of failure. 7 out of 17 described causes as symptoms, and 6 considered long-term consequences as forms of failure as well.

Furthermore, it was found that 10 participants related a cause to a symptom, but did not consider further consequences. Only 3 participants recognised a three-level relationship, such as inexperience (cause) -> need for reworking (symptom) -> loss of reputation (consequence). Most didn't recognise relationships between certain causes and symptoms, or symptoms and consequences that were not immediately obvious. These inconsistencies among participants suggest a need for clear representation and distinction in the three levels of the taxonomy.

Thus, a model of failure taxonomy is proposed, which aims to aid a better understanding of the relationship between the three levels of failure within the domain of experience and knowledge contained within the 19 participants in this research. This model, the development of which is presented in more detail in Velikova et al (2018), is presented in Figure 2 and consists of three concentric circles of different size, joined in the centre to form a three-level rotating tool. The circular shape was selected to encourage holistic thinking as part of a systems engineering approach, and to discourage typical behaviours observed in engineering students such as linear thinking which could lead to consistent instead of a variety of potential outcomes. Each circle contains a different level of the taxonomy, starting from the outermost (causes) to the innermost (consequences).

Figure 2 appears here

At the top of each circle, there is a slot marked with a dashed line. This slot is cut out of the circle and allows different causes to take place, by simply rotating the first circle as shown in Figure 5. Similarly, the other two levels have cut outs, allowing different symptoms and consequences to be placed there. The three cut-outs are joined by a blue arrow, which guides the user into a linear pattern of cause-> symptom -> consequence.

Figure 3 appears here

Rotating circles were chosen to allow exploration of various failure paths by lining up different items from each circle. The importance of such an option was underlined at the interview stage, where it was noticeable that participants did not recognise three levels, or could not connect paths between well-known causes, symptoms and consequences. Although some links are stronger, classic methods for analysis ignore some relationships between causes, symptoms and consequences. Engineering education encourages thinking beyond the immediately obvious and in this situation, it is important to explore various potential failure paths.

It is proposed that the failure analysis tool is produced in a physical form, which will improve its user-friendliness and ease of understanding. Alternatively, it can be transitioned into an online environment, where the user can rotate the circles and manually place different items in the available slots. Such a method could improve the ease of distribution but will remove the opportunity to play with the tool hands-on.

The Failure Taxonomy Tool can only provide an initial overview of the taxonomy of failure. It does not claim to be exhaustive, and project-specific causes would still need to be identified by the analysing engineer. Therefore, the tool presented is a representation of what a failure taxonomy could look like (that is, in answer to our original research question) and does not claim to be universal.

And so, a question remains as to how useful and representative of real engineering systems is it? Is this a model of failure taxonomy that can be recognised? Having proposed an initial representation of this taxonomy, the research team attempted to gain clarity in these questions through the final phase of this research by consulting with six construction industry leaders to discuss potential benefits to the industry as a practical and educational tool, and these are discussed below.

Face validity testing and discussion

If some level of validity and representativeness cannot be established, then there can be no confidence in the deployment of the tool previously presented. Face validity is a non-statistical method to determine the appropriateness or relevance of a given result using experts' opinions (Weiner and Craighead, 2010). Typically, industry experts are shown the model under investigation and asked to discuss and indicate its representativeness to reality and usefulness for deployment.

In this case, six experts were selected who – importantly – were not within the initial pool of 19 interviewees. They had experience of infrastructure delivery and two were industry focussed academics.

Table 2 appears here

The Failure Taxonomy Tool addresses two key issues identified during thematic analysis: lack of distinction between causes, symptoms and consequences of failure, and the unclear relationship between the three levels. Firstly, the tool clearly indicates the three tiers of the failure taxonomy. When presented with the failure identification tool, all six experts expressed interest and overwhelming support for the simplicity of such representation. The use of circles was commended for being easy to grasp, with one expert saying that *''unlike common categorisation, it does not just put things in boxes, but allows fluidity''*. It is believed that by being hands-on, the tool will grab the attention of potential users and encourage them to think about the three levels of failure.

Secondly, the tool represents the relationships between the levels of the taxonomy. While experienced systems engineers may have an all-encompassing view of potential hazards and their manifestation as symptoms and consequences, an inexperienced, narrow-fielded engineer may not. The lack of commercial awareness among recent (civil) engineering graduates was a common criticism from the consulted industry experts. One participant stated that *'understanding risks and the implications of failure is the most useful skill for a graduate engineer'* which certainly coincides with the views of the engineering academic based authors of this paper. Therefore, the tool can aid awareness of potential failure paths, particularly among inexperienced engineers.

An implicit issue identified by thematic analysis that could be solved by the Failure Taxonomy Tool is the lack of forward thinking in the construction industry. Almost all initial participants were able to trace back a failure, but only six of them could project long-term consequences. This problem was reiterated during face validity. Unlike the defence industry, where planning for failure is equally important as planning for success, the construction industry is mostly concerned with backwards thinking. For instance, the Root Cause Analysis method helps with identifying why a failure occurred, but is less useful in determining any action for preventing it. The Failure Taxonomy Tool provides a potential solution by encouraging forward thinking with the use of a unidirectional arrow. The linearity of the failure arrow was most appreciated by the systems engineer, who believed that it would make people explore different combinations of causes, failures and consequences that would otherwise be left unnoticed. Therefore, it has a potential to encourage forward-thinking regarding failure.

The applicability of the Failure Taxonomy Tool to the construction industry was confirmed by all six experts during face validity. Participants confirmed that the tool could be useful in preventing failure by exploring different failure paths. For instance, most engineers will certainly correlate poor design with a structural collapse. However, many inexperienced graduate engineers would be unaware of the commercial or legal consequences that such an initial error may have.

The Failure Taxonomy Tool can therefore provide a beneficial starting point for graduate engineers to think about potential causes of failure, and the long-term consequences of an erroneous assumption or personal negligence. An initial interview participant said *'there should be a course on commercial awareness'*, as most graduate engineers severely lack understanding of the big picture of an engineering project. The intangibility of some consequences makes them harder to identify at an initial stage, therefore causing the analysing engineer to forget or ignore them. The failure identification tool can serve as both a reminder and a learning opportunity to understand the implications of failure in the construction industry.

Conclusions

Failure is an intrinsic part of all engineering, including construction. The views, attitudes, processes and understanding of failure are variable, however, including how to facilitate learning from failure. The research presented here considers the views held by nineteen individual construction professionals in the UK and, through thematic analysis of semi-structured interviews with those individuals, insights have been gained. The key outcomes of these interviews are summarised as:

- Views of failure varied with the nature of that failure. The consideration of safety appeared to be universally accepted as the most predominant form of failure for which action is needed, with less consistent understanding for other forms of failure such as quality, time and money.
- Different levels of maturity in the learning cycle applied to different failure modes within a construction project were observed. While safety showed mature single-loop systematic learning and some migration towards double-loop thinking, quality presented an undeveloped single-loop process. Meanwhile, systematic learning processes were not observed at all for time and money failures, though there was strong evidence of informal learning and discussion.
- Attitude stimuli were observed, first under the broad heading of Ownership and Blame. The prevalence of blame, which is probably recognisable to many in the

industry, has the negative consequence of suppressing further learning – essentially, blame transfers ownership of a failure and thus responsibility for the initial failure and any learning that may come from that failure is declined. These are not ideal conditions for any potential institutionalisation of systematic learning from failure. The converse is posited: increased ownership of failure cultivates a learning environment.

- Further attitude stimuli were observed under the general area of Acceptance and Leadership. The interviews revealed the need for introducing incentives for learning from failure and emphasised the impact of individual and company leadership on acceptance of failure as a possible concept.
- While there was a general understanding of the existence of causal relationships in failure, there were inconsistent views of how failure manifests in subsequent, distal consequences, as well as a lack of appreciation that there can be multiple paths through causes, symptoms and consequences of failure.

These initial findings suggested further work needs to be done in the education of engineers to provide a more consistent and correct view of failure itself and its causes and consequences. Without this adequate bedrock of understanding, the development of a culture of learning from failure will struggle to emerge in the industry. The latter part of this paper therefore focussed on ways in which that education can be facilitated. Analysis of the interviews revealed a lack of systems understanding of failure, together with inconsistent views on what were causes, symptoms and consequences. As a response, a three-tiered taxonomy has been proposed, together with a failure taxonomy tool that aims to represent the taxonomy in a simple, fluid and clear way. This tool has been subject to scrutiny by six industry experts who have concluded the tool provides face validity and usefulness in its representation of failure in our industry.

There are limitations to this work. The first is that insights are gathered from only a small number of professionals involved in UK infrastructure construction. Extrapolation to other geographic and sectoral populations must be done with caution. Another fundamental problem has been the struggle to gather views from a more diverse range of interviewees, almost all of which were white, British males. Only one female has inputted into this work in the total of 25 participants, not including the researchers themselves.

This work has revealed the prevalence of attitudes that are barriers to the development of a culture of learning from failure. At best these barriers might be able to be removed, but in the case of 'blame' this has a more fundamental impact through its removal of any ownership of responsibility for failure and subsequent learning. We conclude therefore that in order to sow the seeds of a wider attitude shift towards systematic learning from failure, much needs to be done to develop better systematic understanding and more positive attitudes to failure in the first place. It is advocated here that this starts in the higher education of built environment and engineering graduates, if not earlier. The need for graduate engineers to *'think failure to prevent failure'* was reiterated by multiple experts during face validity, though all recognised that failure is not commonly discussed in degree programmes. The taxonomy tool presented here is intended to understand what such a taxonomy could look like, and how it might be introduced to students. Further work is needed to develop a broader and more nuanced representation of the construction and engineering sector, and to understand how students themselves react to the concept of failure. Inclusion of this in the higher education engineering curriculum could improve awareness of the topic, in a manner similar to that seen for both construction safety in the 1980s and sustainability in the early 2000s, novel concepts at their time. Similarly, in a 10-15 year span, failure analysis could become an inseparable part of engineering design, instead of simply a bureaucratic nuisance, enabling students and professionals to fail better.

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Figure and Table Captions:

Figure 1 The Failure Life Cycle

Figure 2 The Failure Taxonomy

Figure 3 How to use the Failure Taxonomy Tool

Table 1 Interviewees

Table 2 Face validity experts (all experts aged 50+)

References

Ahiaga-Dagbui D., Love P., Smith S. and Ackermann F. (2016) Toward a Systemic View to Cost Overrun Causation in Infrastructure Projects: A Review and Implications for Research. *Project Management Journal*, 48(2), 88-98.

Argyris C. and Schön D.A. (1996) *Organizational Learning II: Theory, Method and Practice*. Reading, Massachusetts: Addison-Wesley.

Boulding, K. and Khalil, E. (2002). *Evolution, order and complexity*. Taylor and Francis, London, UK

Braun, V. and Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2): pp. 77–101.

Bye R.J., Rosness R. and Røyrvik J. (2015) 'Culture' as a tool and stumbling block for learning: The function of 'culture' in communications from regulatory authorities in the Norwegian petroleum sector. *Safety Science*, 81, 68-80.

Cannon, M. D., & Edmondson, A. C. (2005). Failing to learn and learning to fail (intelligently): How great organizations put failure to work to innovate and improve. *Long range planning*, *38*(3), 299-319.

Carter, G., & Smith, S. D. (2006). Safety hazard identification on construction projects. *Journal of construction engineering and management*, *132*(2), 197-205.

Drupsteen, L. and Guldenmund, F. W. (2014) What is learning? A review of the safety literature to define learning from incidents, accidents and disasters. *Journal of Contingencies and Crisis Management*, 22(2), 81-96.

Duryan, M., Smyth, H., Roberts, A., Rowlinson, S., & Sherratt, F. (2020). Knowledge transfer for occupational health and safety: cultivating health and safety learning culture in construction firms. *Accident Analysis & Prevention*, *139*, 105496.

Ferdous, R., Khan, F., Sadiq, R., Amyotte, P., & Veitch, B. (2013). Analyzing system safety and risks under uncertainty using a bow-tie diagram: An innovative approach. *Process Safety and Environmental Protection*, *91*(1-2), 1-18.

Harreveld, B., Danaher, M., Lawson, C., Knight, B. A., & Busch, G. (Eds.). (2016). *Constructing methodology for qualitative research: Researching education and social practices*. Springer.

Haslam R.A., Hide S.A., Gibb D.E., Gyi D.E., Pavitt T., Atkinson S. and Duff A.R. (2005) Contributing Factors in Construction Accidents. *Applied Ergonomics*, 36, 401-415

Health and Safety Executive (2013). *RIDDOR - Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013*. https://www.hse.gov.uk/riddor/ (Accessed 7 July 2021)

Hewlett, B. (2020). Briefing: Temporary Works Forum: how history and narrative shaped a major safety initiative. *Proceedings of the Institution of Civil Engineers-Forensic Engineering*, *172*(2), 57-60.

Hinze, J., Pedersen, C., & Fredley, J. (1998). Identifying root causes of construction injuries. *Journal of Construction Engineering and Management*, *124*(1), 67-71.

Kolb D.A. (2015) *Experiential Learning: Experience as the Source of Learning and Development. Second Edition.* Pearsons Education, Inc. New Jersey.

Lloyd-Walker B.M., Mills A.J. and Walker D.H.T. (2014) Enabling construction innovation: the role of a no-blame culture as a collaboration behavioural driver in project alliances. *Construction Management and Economics*, 32(3), 229-245.

Lopez, R., Love, P., Edwards, D., and Davis, P. (2010). Design Error Classification, Causation, and Prevention in Construction Engineering. *Journal of Performance of Construction Facilities*, 24(1): pp. 399–408.

Love P.E.D., Teo P., Carey B., Sing C-P., and Ackermann F. (2015). The symbiotic nature of safety and quality in construction: Incidents and rework non-conformances. *Safety Science*, 79, 55-62.

Love, P. E., Edwards, D. J., & Irani, Z. (2008). Forensic project management: An exploratory examination of the causal behavior of design-induced rework. *IEEE Transactions on Engineering Management*, *55*(2), 234-247.

Munier N. (2014) *Risk Management for Engineering Projects*. Springer International Publishing.

Nikolova I., Ruyssevelt J.V., Witte H.D. and Dam K.D. (2014) Learning climate scale: Construction, reliability and initial validity evidence. *Journal of Vocational Behaviour*, 85(3), 258-265.

O'Hare, D. (2000) The ‘Wheel of Misfortune’: a taxonomic approach to human factors in accident investigation and analysis in aviation and other complex systems, *Ergonomics*, 43:12.

Petroski, H. (1985) *To Engineer Is Human: The Role of Failure in Successful Design*. London: Macmillan.

Plant, K. and Stanton, N., 2017. The development of the Schema-Action-World (SAW) taxonomy for understanding decision making in aeronautical critical incidents. *Safety Science* 99 (9), 23–35.

QSR International Pty Ltd. (2018) NVivo (Version 12), https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home (Accessed 7 July 2021)

Reason J. (1990) *Human Error*. Cambridge University Press, Cambridge, UK.

Reason, J.T. and Hobbs, A. (2003). *Managing maintenance error: A practical guide*. Ashgate Publishing Company, Aldershot UK

Sage, D., Dianty, A., and Brookes, N. (2014). A critical argument in favor of theoretical pluralism: project failure and the many and varied limitations of project management. *International Journal of Project Management*, 32(4): pp. 544–555.

Sanne J.M. (2008) Incident Reporting or Storytelling? Competing schemes in a safety-critical and hazardous work setting. *Safety Science*, 46: 1205-1222.

Silva S. and Lima M.L. (2005). Safety as an organisational value: improving safety practices and learning from accidents. In Kolowrocki K. (Ed.) *Advances in Safety and Reliability*. Vol 2. Taylor & Francis, London, 1817-1824.

Silverman, D. (2013). *A very short, fairly interesting and reasonably cheap book about qualitative research*. Sage.

Soane A. (2015). Cross-Confidential Reporting on Structural Safety. *Seventh Congress on Forensic Engineering*, November 15–18, 2015, Miami, Florida, ASCE, 620-627.

Stemn E., Bofinger C., Cliff D., and Hassall M. E. (2018) Failure to learn from safety incidents: status, challenges and opportunities. *Safety science*, 101, 313-325.

Velikova, M, Baker, H and Smith, S D (2018) The Meaning of Failure: Establishing a Taxonomy of Failure in the Construction Industry to Improve Organisational Learning In: Gorse, C and Neilson, C J (Eds) *Proceeding of the 34th Annual ARCOM Conference*, 3-5 September 2018, Belfast, UK, Association of Researchers in Construction Management, 16-25.

Wanberg J., Harper C., Hallowell M.R., and Rajendran S. (2013). Relationship between Construction Safety and Quality Performance. *Journal of Construction Engineering and Management*, 139(10).

Wantanakorn, D., Mawdesley, M.J., and Askew, W.H. (1999). Management errors in construction. *Engineering, Construction and Architectural Management*, 6(2) 112–120.

Weiner, I.B. and Craighead, W.E. 2010. *The Corsini Encyclopedia of Psychology*, Volume 2, 4th Edition, Wiley.

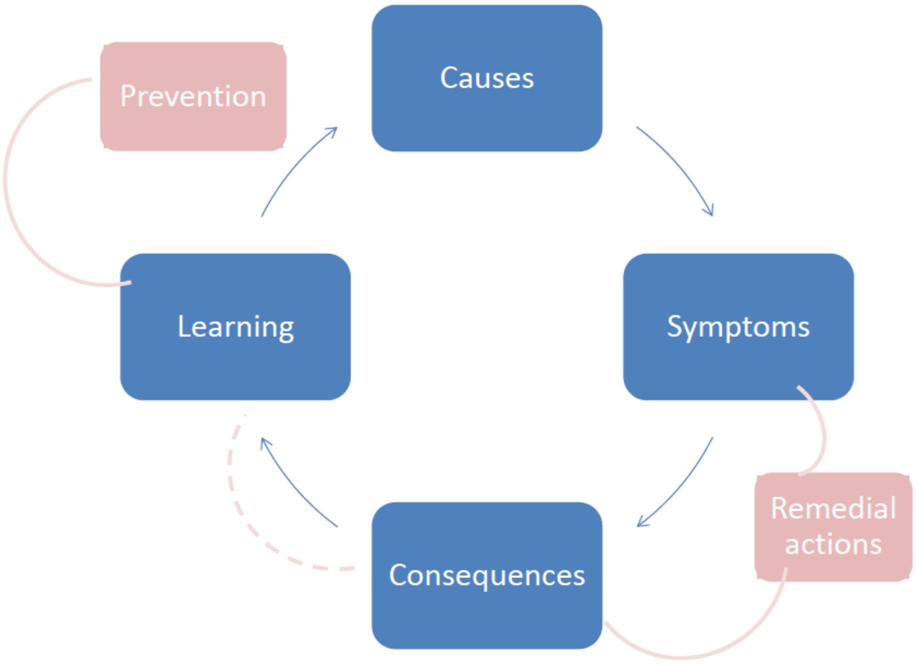

Figure 1 The Failure Life Cycle

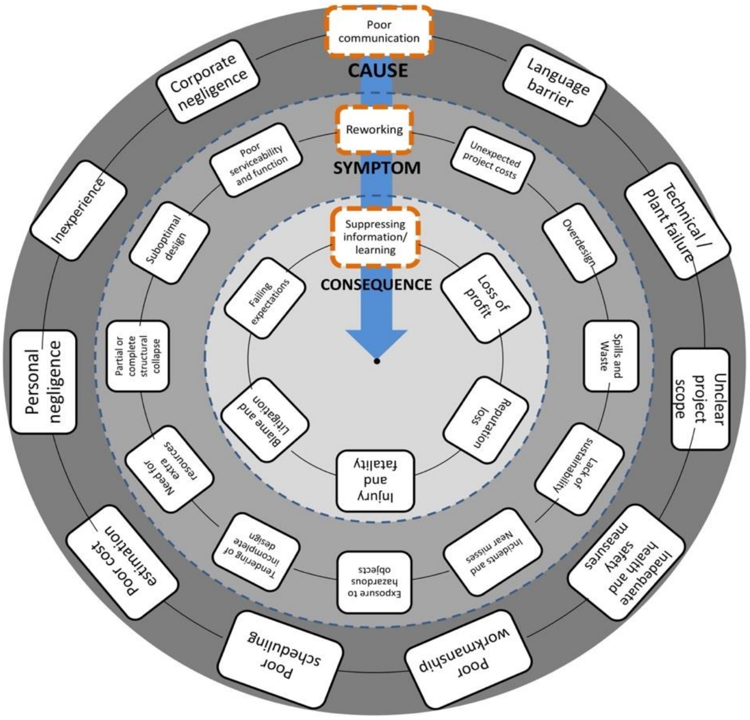

Figure 2 The Failure Taxonomy

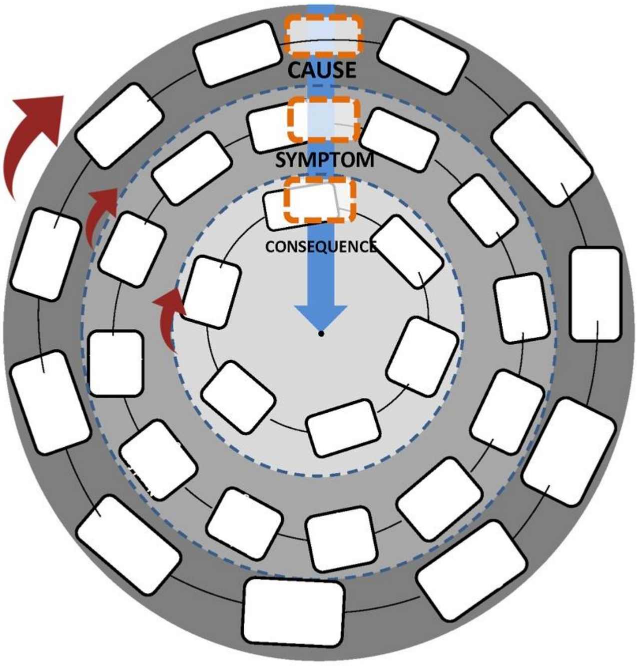

Figure 3 How to use the Failure Taxonomy Tool

Table 1: Interviewees

Interviewee Number	Time in Industry	Age	Gender	Sector	Title
1	26	45-55	Male	General Infrastructure	Technical Director of Infrastructure
2	28	45-55	Male	Rail	Programme Director
3	7	25-35	Male	Rail	Head of Programme Management
4	15	35-45	Male	Rail	Senior Project Engineer
5	30	45-55	Male	Rail	Senior Design Manager
6	20	35-45	Male	General Infrastructure	Group Learning Manager
7	20	45-55	Male	General Infrastructure	H&S Advisor
8	50	55+	Male	Renewables	H&S Manager
9	25	45-55	Male	General Infrastructure	Exec Corporate Development
10	27	45-55	Male	Rail	Programme Manager
11	31	45-55	Male	Rail	Quality and Reliability Manager
12	10	45-55	Female	General Infrastructure	Environmental and Sustainability Manager
13	3	<25	Male	Rail	Graduate Business Improvement Engineer
14	13	25-35	Male	Renewables	Site Manager
15	34	55+	Female	General Infrastructure	Commercial Services Director
16*	35	55+	Male	Renewables	Client Representative
17*	15	35-45	Male	Renewables	Client Representative
18	19	35-45	Male	Structural Design	Technical Director
19	25	45-55	Male	Structural Design	Commercial Director

*No transcript of interview (i.e. permission for recording not granted)

Table 2 Face validity experts (all experts aged 50+)

Expert	Gender	Sector	Title
1	M	Rail	Technical Director of Infrastructure
2	M	Rail	Senior Systems Engineer
3	M	Rail	Construction Design Manager
4	M	Rail	Project Director
5	M	Rail	Chair of several institutions; Academic
6	M	Structural Engineering	Business Leader; Visiting lecturer