THE MEANING OF FAILURE: ESTABLISHING A TAXONOMY OF FAILURE IN THE CONSTRUCTION INDUSTRY TO IMPROVE ORGANISATIONAL LEARNING

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Despite years of construction accidents and thousands of filed reports, failure is still poorly understood. There seems to be a general disagreement in the field of what constitutes failure. Authors attribute it to, amongst other factors: deficient management; cost and time overruns; design and human error. Developing an understanding of the underlying definitions and links behind failure in construction will allow industry leaders to communicate more effectively about failure and advance industry-wide learning. To better understand the levels of failure in the construction industry, 17 semi-structured interviews were conducted with members of the community across various business aspects and sizes. The aim was to explore the meaning of failure and create a taxonomy which can be used to aid understanding. Thematic analysis revealed a three-level causal relationship between causes, symptoms and consequences of failure. A three-tiered taxonomy of failure was developed, and represented visually in the form of the Failure Taxonomy Tool. It allows for the clear distinction between the three levels of failure and relationships between them, and encourages exploration of both well-known and rare failure paths. The Failure Taxonomy Tool can be used to supplement existing risk analysis methods and encourage forward-thinking. Its applicability in the construction industry and higher engineering education was supported by industry experts via a face validity exercise. Potential applications include, but are not limited to, identifying risks to project success during project inception; becoming a part of graduate programmes to improve commercial awareness; encouraging discussion about popular and unexplored failure paths; as well as serving as an aid to improve students' awareness of failure. Better understanding of failure is the first step to minimising construction project risks and long-term losses.

Keywords: communication, failure, systems engineering, taxonomy

INTRODUCTION

In the light of the Carillion (one of the largest construction companies in the UK) liquidation on 15th January 2018, it is more important than ever to not only understand failure but to also acknowledge it. What appeared to be a huge surprise to thousands of workers, suppliers and the general public appears to have been known within high levels of the company for many months. The reluctance to acknowledge

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and discuss failures might have contributed to the breakdown of the company. Keeping company's issues 'behind closed doors' has definitely proven unsuccessful.

The reluctance to discuss failure is closely associated with the negative connotations it evokes. Despite decades of structurally sound construction, it is precisely the grand structural failures that linger in society's memory (Petroski, 1985): the Tahoma Narrows, the Hyatt Regency, and more recently the Rana Plaza collapse. All these events have diminished the construction industry's authority, and created an unbreakable association between the industry and failure.

Despite years of construction accidents and thousands of filed reports, it is still staggering that failure is poorly understood. There seems to be a general disagreement in the field of what constitutes failure, with authors providing different definitions and attributing it to factors such as deficient management (Sage *et al*., 2014), cost and time overruns (Sun and Meng, 2009), design (Lopez *et al*., 2010)) and human error (Dekker, 2006). The general absence of failure discussion from the engineering education curriculum further inhibits engineers' understanding of the phenomenon.

By developing a deep understanding of the levels and breadth of types of failure, the construction industry can begin to educate its members and raise awareness about its impact. Using 17 in-depth semi-structured interviews with members of the construction industry, the research presented here explores the different levels of failure and the relationships between them. A three-tiered taxonomy of failure is developed, and represented in a Failure Taxonomy Tool. The aim of this tool is to aid understanding and learning about failure in higher education and industry environments.

APPROACHES TO UNDERSTANDING FAILURE

There is 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). Moreover, failure is often referred to as 'error', 'mistake', 'risk' 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 which cannot be simply defined 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), a 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.

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 showcase 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 aeronautic industry in a similar manner that this research aims to improve the construction industry.

Therefore, taxonomy could be used to aid understanding of failure, which in turn can be increasingly helpful in preventing it, since forensic examination of failure causes can decrease the chance of recurrence (Love *et al*., 2008).

METHODOLOGY AND METHODS

In order to satisfy the primary aim of the research - to produce a tool for failure understanding which can be used across the construction industry in the UK, realist stance is taken. It is important to acknowledge the role of the researcher in relation to his or her impact on the research being carried out, which is of great importance in qualitative research (Silverman 2007). Lack of bias has been attempted as the researcher is not part of the construction industry at the time of writing, and has limited exposure to the industry itself. This allows taking a scientific, academic stance rather than a role of an active participant in the construction industry.

This research was based on a three-step method. Firstly, data were primarily collected by Baker *et al*., (2018) in the form of 17 semi-structured interviews with people in various levels and aspects of the construction industry. The interviewees were approached through mutual professional acquaintances. This form of interview was selected as it allows fluidity in discussions, including clarifying questions, while ensuring the relevant topic areas are covered (Harreveld *et al*., 2016).

Secondly, data was processed using thematic analysis based on the approach outlined by Braun and Clarke (2006) using spatial prevalence to identify themes. The active position of the researcher who determines the 'themes' in thematic analysis needs to be considered. A qualitative data analysis software - NVivo - was used to code the data set. Initially, over 30 'themes' were identified, which were narrowed down to three main ones and transitioned into taxonomy and later into a tool.

Finally, to verify the observed results, six industry experts (different from interview participants) took part in a face validity exercise. This is a non-statistical method to determine the appropriateness or relevance of a given result using experts' opinions (Weiner and Craighead, 2010). The experts were shown the finished tool and asked to discuss the clarity of communication, as well as its usefulness to the industry. Suggestions on how to improve it were implemented and led to the final version of the Failure Taxonomy Tool.

Thematic Analysis Results

Thematic analysis of the 17 interviews revealed that participants recognised the existence of causal relationships in failure. The most commonly mentioned 'failures' were classified as either causes, symptoms or consequences, which became the basis of a three-tiered failure taxonomy. The taxonomy was included into a broader failure lifecycle, presented in Figure 1. It consists of all the elements participants mentioned when discussing failure. Aspects such as learning and prevention of failure, albeit important, are not considered as part of this research - readers are referred to Baker *et al.*, (2018) for more details on learning from failure.

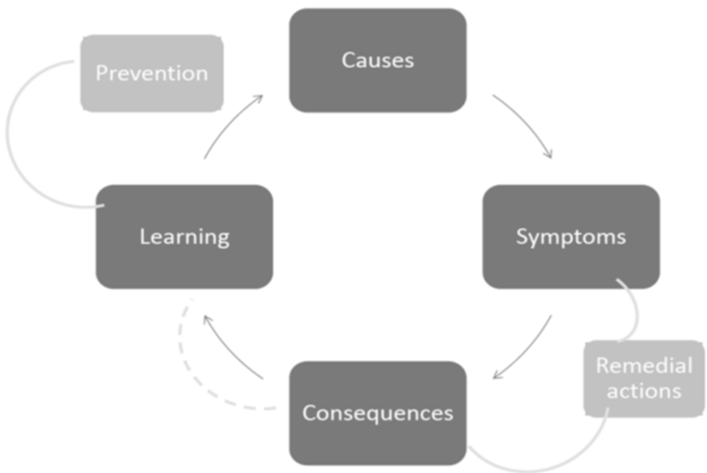

Figure 1: The Failure Life Cycle

In the failure taxonomy, causes are factors which have the potential to result in a failure. They could be due to technical, planning, personal or communication issues, which all fall under the category of 'organisational' causes.

The second level of failure are symptoms. It was decided that failure symptoms are processes that can be observed, similarly to the medical field. They refer to 'lack of project success' in terms of one or more pillars of a successful project (cost, time, quality, environment and safety). These are all actions that are encountered usually before a project is considered complete and usually have a defined 'finish' point.

The third level of the failure taxonomy refers to consequences which are the long-term effects from a failure symptom. They could be tangible (like loss of profit), or intangible, such as loss of reputation.

As the research aims to create a practical tool for understanding failure, the three tiers of the taxonomy were identified, and relationships between them examined. Thematic analysis revealed that research participants recognised 12 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. It further confirms the need for clear representation and distinction in the three levels of the taxonomy.

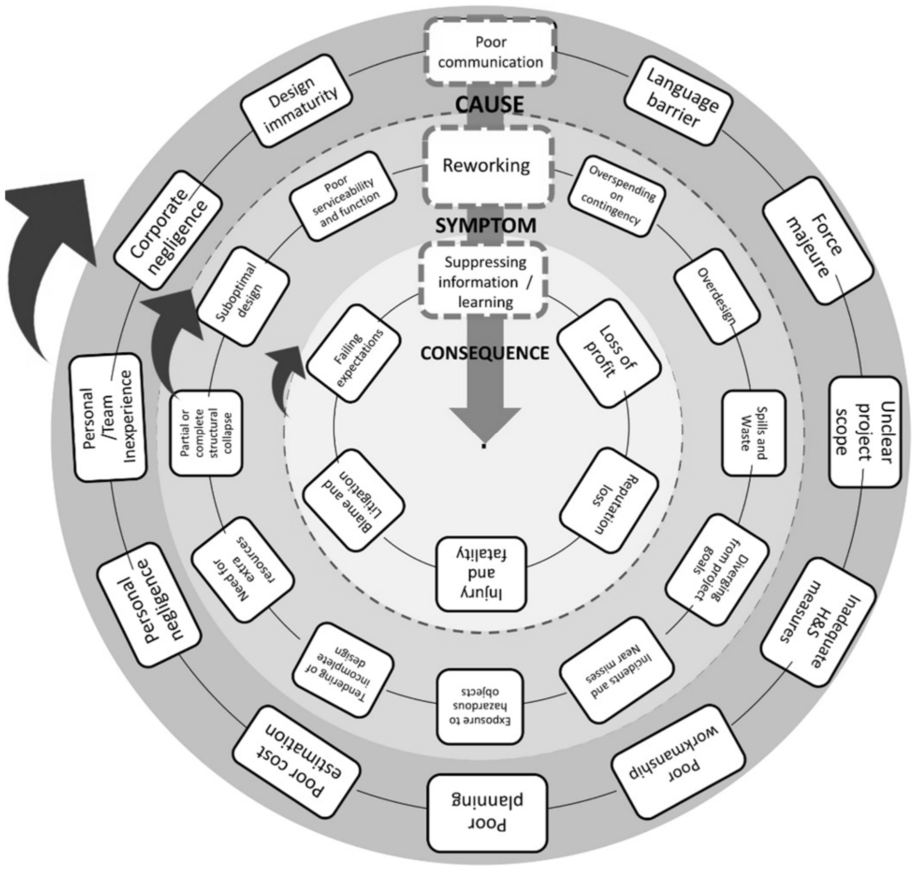

Figure 2: The Failure Taxonomy Tool

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.

The Failure Taxonomy Tool aims to aid a better understanding of the relationship between the three levels of failure. The tool 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 engineering behaviours such as linear thinking and 'boxing' of similar items (Dym, *et al.*, 2005). Each circle contains a different level of the taxonomy, starting from the outermost (causes) to the innermost (consequences).

At the top of each circle, there is a slot cut out of the circle, which allows different causes to take place by simply rotating the first circle. Similarly, the other two levels can be rotated, allowing different symptoms and consequences to be explored. The three cut-outs are joined by a blue arrow, which guides the user into creating a linear failure path of a cause-> symptom -> consequence.

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 besides the well-known ones. Although some links are stronger, classic methods for analysis ignore some relations between causes, symptoms and consequences. Since education is about thinking beyond the immediately obvious, it is important to explore various potential failure paths. It is planned that the Failure Taxonomy Tool is produced in a physical form, which will improve its user-friendliness and ease of understanding.

The Failure Taxonomy Tool can only provide an initial overview of the taxonomy of failure. It does not claim exhaustiveness, and project-specific causes could be added in empty boxes in each level (not shown here for simplicity). This would allow for customisation and help to cater to different engineering branches which may have slightly different needs and modes of failure.

Having produced a version of the tool, the research team consulted with six construction industry experts with experience in both higher education and industry. The aim was to discuss potential benefits to the industry as a practical and educational tool, which are discussed below.

Exploring the Benefits of the Tool through Face Validity

Six experts were consulted to form opinions on the usefulness and benefits of the developed tool. These experts were selected through mutual acquaintance and all had considerable experience of high level of management and leadership in the industry.

When presented with the failure identification tool during a face validity exercise, 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.

The tool represents the relationships between the levels of the taxonomy, the intention being to make it easier for users to appreciate potential hazards and their manifestation as symptoms and consequences. However, a common criticism of a few of the experts concerned the lack of commercial awareness among recent (civil) engineering. One participant stated that 'understanding risks and the implications of failure is the most useful skill for a graduate engineer' which coincides with the conclusions of King (2009) who discussed in a similar manner the lack of big picture understanding of risks and failure among engineering graduates. Therefore, the tool can aid awareness of potential failure paths, particularly among inexperienced engineers and students.

Industry Applications

It was suggested by one of the consulted experts that the tool could be used during project inception. At the project briefing stage, large and medium sized projects begin with a layout of project aims and objectives, followed by potential health and safety risks, and the environmental impact of the works. In this expert's view, the failure taxonomy and failure analysis in general would fit in perfectly at such an early stage, because they provide a certain level of awareness of what the project risks may be. In addition, the failure taxonomy can directly relate to project goals, such as generating profit, safe construction and sustainability. Therefore, the Failure Taxonomy Tool can be used as a big picture tool to gain an overview of immediate and non-obvious risks that need to be avoided. While is requires an honest discussion, the tool allows all parties to raise their doubts, and facilitates the role of the project manager.

The applicability of the Failure Taxonomy Tool in the construction industry was supported by all six experts during face validity. Participants confirmed that the tool can be useful in preventing failure by exploring different failure paths. While it could be argued that the currently used methods of Bowtie analysis and the Swiss cheese model already fulfil this task, both methods require an initial input of hazards by the analysing engineer. If a young or inexperienced engineer is in charge of analysis, they may not be aware of all potential risks and consequences to a project. Therefore, an important omission of a cause, symptom or consequence can occur, while emphasis may be placed on an unlikely failure path.

The Failure Taxonomy Tool provokes discussion about the likelihood and importance of certain failure paths. For instance, most engineers will certainly correlate poor design with a structural collapse. However, it was argued by the industry experts that in the UK, complete or partial collapse of a structure is in fact rare. More often a project is deemed as a failure when, for example, profit or reputation is lost, or the client takes legal action against the contractor. However, many graduate engineers would be unaware of the commercial or legal consequences an initial error may have. This further confirms the need for the tool, as it allows exploration of various failure modes without putting an emphasis on any single path.

The Failure Taxonomy Tool can provide an extremely 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 interview participant said that '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 inexperienced engineers to forget or ignore them. The Failure Taxonomy Tool can serve as both a reminder and a learning opportunity to understand the implications of failure in the construction industry.

Higher Education Applications

The need for graduate engineers to 'think failure to prevent failure' was reiterated by multiple experts during face validity. However, it was suggested that the problem lies in higher education, where failure is not commonly discussed. This leads to lack of experience in areas such as meeting profit targets, or avoiding reputation loss, blame and litigation. Currently, the engineering curriculum in UK higher education is governed by two documents - UK-SPEC and AHEP. While risk analysis is usually touched upon in the learning outcomes provided in the latter, it is rarely in terms of 'risks to project success'. More often, it is referring to immediate physical risks before laboratories and site visits, therefore leaving out the intangible risks leading to project failure, such as lack of communication or inexperience.

Moreover, it appears that current civil engineering curricula in higher education are primarily focused on codes of practice and standards. Much of the taught content still revolves around limit state design. In areas such as soil and structural mechanics, the Eurocodes provide standardised methods for determining if a structure is safe. The Ultimate Limit State (ULS) concerns avoiding structural failure, while the Serviceability Limit State (SLS) touches on aspects of unacceptable quality, such as deflection or vibrations. Compliance with both limit states is required before a building warrant can be issued for a construction project. Therefore, there is heavy academic focus on these topics, usually ranging from the basic factor of safety in early years, to full design in accordance with the Eurocodes in subsequent years.

However, there is a lack of a commercial limit state, where aspects such as avoiding failure could be introduced. During face validity, most experts claimed that they were not taught about failure in the same sense that they use it during their everyday work. This poses a large gap between what is currently taught in higher education, and what the industry demands. As discussed above, experts reiterated the need for civil engineering graduates to be commercially aware. Therefore, there needs to be a part of the academic curriculum which touches on the commercial targets of a project, which can be represented well by the Failure Taxonomy Tool.

During discussions on the applicability of the tool in an academic setting, there were two main suggestions on how the tool could be implemented in higher education. Firstly, the tool can be used as part of workshops or seminars aimed at raising awareness of failure. For instance, it was suggested that participants could be given one specific symptom, and asked to choose a failure path they consider possible. With 72 combinations possible, it is very likely that in a group of 4-5 people, there will be at least a few different failure paths. In this way, the tool could become the basis of a discussion about those paths, and why people connected the same symptom with different causes and consequences. It would allow participants to see that what may be an obvious failure path for one person may be extremely difficult to conceive for another. Thus, the tool can not only help people 'think failure to prevent failure', but to also highlight the differences in the thought process between engineering students, even ones from seemingly similar backgrounds.

It is anticipated that an inclusion of failure in the higher education engineering curriculum can improve awareness of the topic. Similar to failure, both construction safety in 1980s and sustainability is the early 2000s were novel concepts at their time. Yet, nowadays in the UK occupational health and safety, as well as designing projects to abide to the Environmental and Sustainability Regulations lie at the core of every engineering project. Similarly, in a 10-15 year span, failure analysis could become an inseparable part of engineering design, instead of simply a bureaucratic nuisance.

CONCLUSIONS

This work addresses the concerns raised by some authors on the inability of systems and engineering classification approaches to unify discussions on failure. Using a thematic analysis on 17 semi-structured interviews, three-level taxonomy of failure was created to establish the relationships between causes, failure symptoms and long-term consequences and improve understanding of failure.

The Failure Taxonomy Tool aims to represent the three-tiered taxonomy in a simple, fluid and clear way. By exploring known and unexpected combinations of causes, processes and consequences, engineers can gain a wider understanding of the risks and the implications of failure in the construction industry. The tool can provide a beneficial starting point for graduate engineers to think about potential causes of failure, and the consequences of poor decision-making. Furthermore, the tool can aid commonly used tools for risk analysis in construction projects such as Bowtie analysis or the Swiss cheese method by giving an initial list of potential threats and consequences. Finally, the tool and taxonomy can be included in higher education curriculum in numerous ways to encourage engineering students to think about the commercial implications of failure.

However, the Failure Taxonomy Tool has a few limitations. The language of the tool may need to be adjusted to its audience, since construction workers use different jargon to managing directors. In addition to that, with the globalisation of construction projects in UK, translation may be required for workers not yet fluent in English. Moreover, the tool is not exhaustive. Additional empty boxes could be added to allow for each institution to add project-specific causes and symptoms. However, the long-term consequences are anticipated to stay relatively similar. Finally, the tool is most effective when used hands-on, therefore it may need to be distributed and cause accessibility issues. Nevertheless, it is believed that the tool can provide benefits to the industry, so any limitation can be easily overcome.

In conclusion, although not without its limitations, the failure taxonomy and the tool are novel pieces of work which address the deficiencies of currently employed failure analysis models. Employing the taxonomy and the tool in the construction industry or the higher education engineering curriculum can increase awareness and understanding of failure, which in turn can be the first step to minimising construction project risks and long-term losses. Therefore, the importance of this research cannot be overstated, and further work in developing the Failure Taxonomy Tool beyond this project is encouraged.

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