# RETHINKING INFRASTRUCTURE SUPPLY CHAIN MANAGEMENT – A MANIFESTO FOR CHANGE

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**Abstract**

Infrastructure projects exemplify engineer-to-order supply chains, where there is a high degree of complexity and uncertainty associated with developing a 'unique' product. While there is much advocacy of translating operational excellence techniques from high volume manufacturing sectors, we argue that such an approach is based on a mis-presumption of order and structure at all systems levels. We suggest an alternative 'travel of an idea' from the knowledge management discipline, a phenomenological framework describing contexts in terms of ordered and un-ordered, which directs us towards the need for diverse management approaches if we are to minimise the risk of project underperformance and failure. We contemplate the value of the framework and reflect on the contribution it can make to the construction industry specifically and to engineer-to-order production systems more generally; we provide a basis to bring healthy challenge when 'travelling ideas' and expose how unthinking choices can be expected to fail.

**keywords** - Complex systems, Risk management, Engineer-to-order systems, Cynefin

## 1. Introduction

This position paper contributes to ongoing discussions regarding future directions of engineer-to-order (ETO) research (e.g. Hicks et al., 2001, Gosling and Naim, 2009, Iakymenko et al., 2020), with infrastructure supply chains given as an exemplar of such systems (Gosling et al., 2015, Gosling et al., 2017). ETO supply chains are generally project based and are particularly susceptible to risk due their complexity and the degree of innovation required due to their one-of-a-kind, or 'first-of-a-kind', production with little precedence in design solutions. Much of the research on how to reduce risk and uncertainty management has focussed on non-ETO supply chains, such as in the food and automotive sectors (Childerhouse and Towill, 2004, Aitken et al., 2016).

Infrastructure projects are also of such a scale that they often receive considerable public attention especially if there are quality problems, schedule overruns and cost escalations. In the UK, the National Audit Office often notes such issues, for example, with recent Ministry of Defence infrastructure programmes seeing increased total costs of 115% compared to initial projections and individual projects overrunning by 1.7 to 6.3 years (Comptroller and Auditor General, 2020), noting that the substantive contributory factors include risks associated with poor requirements capture and immature designs before construction commences. In addition, it is not uncommon for government clients to build in contingency to budgets as a just-in-case scenario for project overruns, for example, of up to 30% for a major tunnelling project (Comptroller and Auditor General, 2017). The problems faced are applicable internationally, with infrastructure cost overruns, identified in developed and developing countries, ranging from 5.4% to 62.2% (Herrera et al., 2020). And they are not new – Flyberg (2014) provides an historical perspective noting that megaprojects in particular overrun by 50% (Great Belt East Bridge, Denmark, 1991-1998) up to a staggering 1,900% (Suez Canal, Egypt, 1859-1869). At the core of such overruns is that, although such projects tend to be highly complex and are therefore inherently uncertain, often they are managed by organisational forms and have goals that are constructed too simplistically (Salet et al., 2013).

The construction sector has often looked to learn from manufacturing, and especially the 'lean' ethos, where the dominant logic is based on particular contextual assumptions. Studies of construction tend to fall into one of two camps: the first proposes concepts, tools and techniques intended, or originally conceived for, a stable world where time and cost allocation can be orderly, and progress is (or certainly should be) predictable, logical and summative (Egan, 1998); the other camp assumes that the world is primarily complex (Aritua et al., 2009, Shadid, 2018). *In reality, there are shades of grey; in any case we need to acknowledge that what is straightforward, or simple to do, for one person (for* *example an expert) is baffling or impossible for another. Contexts might be driven by the specific technical challenge, but they might be driven or created by people, their behaviour, the contract, social factors and so forth.* If unrealistic or inappropriate contextual assumptions prevail, there is a danger that the wrong management approach is applied, increasing the risk of project failure (Denicol et al., 2020).

The travel of an idea, for instance through transfer of 'best practice', lesson drawing or the adaptation of general concepts, is an important concern for the construction sector and a matter for considerable debate. Based on the travel of ideas from other disciplines (Morris and Lancaster, 2005), we look to the Cynefin phenomenological framework developed in the knowledge management discipline (Kurtz and Snowden, 2003, Snowden and Boone, 2007) to allow us to assess a contingency approach to the management of construction supply chains. *Their framework is particularly suitable to assess and challenge the orthodoxy prevalent in construction supply chains (Denicol et al., 2020), and project environments more generally (Ramasesh and Browning, 2014), where very often plans, reports, strategies and business cases are, sometimes implicitly, presented with the assumption of order. Cynefin has been recognised as making key contributions to decision theory and performance alignment (Alexander et al. 2018), as well as having important implications for risk and decision analysis (French 2015). Importantly, Cynefin also recognises that decision making in organisational contexts is typically undertaken between groups of people, perhaps with different levels of experience and worldviews, who need to facilitate their collective sensemaking of a decision context (Kurtz and Snowden, 2003).*

Other disciplines have exploited Cynefin, most notably in information science and technology (e.g. McLeod and Childs, 2013, Lepmets et al., 2014) and healthcare (e.g. Fulop and Mark, 2013), with some examples in general project management (Shalbafan et al., 2018) and supply chain management (Alexander et al., 2014). A common theme emerging form those studies, as well as the original works (Kurst and Snowden, 2003, Snowden and Boone, 2007), are that the benefits of Cynefin are articulated in qualitative terms. A key benefit is for project stakeholders to have a shared understanding of the types of problems faced, their causes and solutions (Fulop and Mark, 2013, McLeod and Childs, 2013), agreed goals and targets (Lepmets et al., 2014) and action plans (Shalbafan et al., 2018), and identification of the appropriate problem solving tools (Alexander et al., 2014). *Nevertheless, given that forcing simplistic management approaches has substantive negative quantitative impacts on complex projects especially with project schedule and budget overruns (Salet et al., 2013), we believe that the Cynefin framework gives decision-makers the opportunity to reflect on adopting right sized management tools, techniques and interventions for the specific situation they face.*

A classic example of determining the most suitable approach in supply chains is in risk management (Jüttner et al., 2003) at both micro- (specific activities) and macro- (supply network) levels (Singh, 2020). Risk management has tended to emphasise quantitative models and approaches, often assuming an orderly world (Ramasesh and Browning, 2014), although there is little evidence that such methods have a positive impact on project performance (Hubbard, 2020), with issues associated with calibration of scoring methods, lack of common understanding of the meaning of risk and little value on decision making by project team members. Alternative qualitative approaches, that consider hypothetical failure scenarios prior to the start of a project (Klein, 2007) are more aligned to organisational studies that argue that narratives are more effective in the management of complex environments (Williams, 2008). Nevertheless, we would argue that there is currently no existing decision-making framework to allow supply chain managers generally, and those in the construction industry specifically, to decide which method is most appropriate for their specific ETO environment.

Hence, we aim to *ascertain the relevance of the Cynefin framework in challenging the current orthodoxy that infrastructure projects can be managed based on the assumption of order, with the purpose of recommending the framework's exploitation with implications for practice and academe.* In doing so, we also reflect on the broader implications for ETO project-based supply chains and the necessity for diverse management approaches in risk management where there is a high degree of complexity and uncertainty.

We, an interdisciplinary authorship team from industry and academe, exploit a cooperative enquiry approach (Heron, 1996). The industry practitioner brings 30+ years of practical experience in construction management, including senior positions in the private sector, substantive roles in professional civil engineering bodies and membership of national committees considering risk and uncertainty. One of the academics is a social scientist with expertise in the management of ETO supply chains, having previously worked in the automotive sector before obtaining his PhD. The second academic has a first degree in civil engineering but with an academic career that has developed systems engineering tools and techniques to enhance the performance of logistics systems. Together, we contemplate the value of the Cynefin, citing its referencing and/or exploitation in relevant previous research, using a "discursive alignment of interpretation" (Seuring and Gold, 2012), and reflect on its meaning for the construction industry.

Such reading, interpretation and reflection was complemented by credibility checking of our thoughts at an industry workshop on complexity and academic critique at a logistics conference, occurring over a period of eight years and led to a unified position paper as presented here. The Cynefin framework, identified by the academic authors, particularly resonated with the author from practice. Especially pertinent is the practitioner author's observations of engineering and management practices misaligned with the encountered problems. Hence, our narrative citing the relevant literature is interspersed with our overall experiences of various infrastructure projects and an application using a case developed from secondary data. The latter is of the Edinburgh School case (Cole, 2017) where a catastrophic failure of a cavity wall occurred during a violent storm. We have chosen this case study as it has been well documented via a public enquiry report, and it provides much evidence that may be aligned with the Cynefin framework that allows us to dissect the implications of decision making based on wrong assumptions about simplicity versus complexity.

Following the above Introduction, in Section 2, we highlight the fundamental characteristics of infrastructure projects and give an overview of the Cynefin framework that makes it relevant to understanding how to manage such ETO supply chains. Then in Section 3 we focus on the generic ETO attributes of infrastructure projects with a specific focus on the Design phase, which is the determining factor to show how Cynefin may be applied in ETO supply chains as given by a notably rare report (Vollmar et al., 2017) on an ETO production case in Section 4. Section 5 critiques the application of Cynefin in the ETO production case (Vollmar et al., 2017) and suggests the nuances required for a more complex infrastructure project environment. In Section 6, we show the relevance of Cynefin in a construction environment before embarking, in Section 7, on its application, via analysis of the of the Edinburgh School case (Cole, 2017) that requires system hierarchy and temporal considerations. Finally, in Section 8 we conclude by proposing a manifesto for how Cynefin may change the construction industry and reflect on how it relates to ETO supply chains.

## 2. The nature of infrastructure projects

Infrastructure projects have distinct attributes when compared to other forms of production e.g. automotive (assemble-to-order or make-to-stock) or retail (ship-to-stock) sectors and, using the primary logic of operations management decoupling-point concept, may be characterised as ETO systems (Gosling and Naim, 2009, Yang, 2013) as shown in Figure 1. The risks linked to lead-times, stock-holding, resource investments, capacity building and total costs, vary from one end of the spectrum to the other (Hoekstra and Romme, 1992). Most supply chain theory has been developed in the assemble-to-order and make-to-stock marketplaces (Gosling et al., 2016), where the risks of stockholding (obsolescence) and stock-out (poor customer service) dominate, and where the design phase is a separate business process. As volumes are relatively high and variety per unit of product is low then batch, line and process production forms are appropriate (Hayes and Wheelright, 1979).

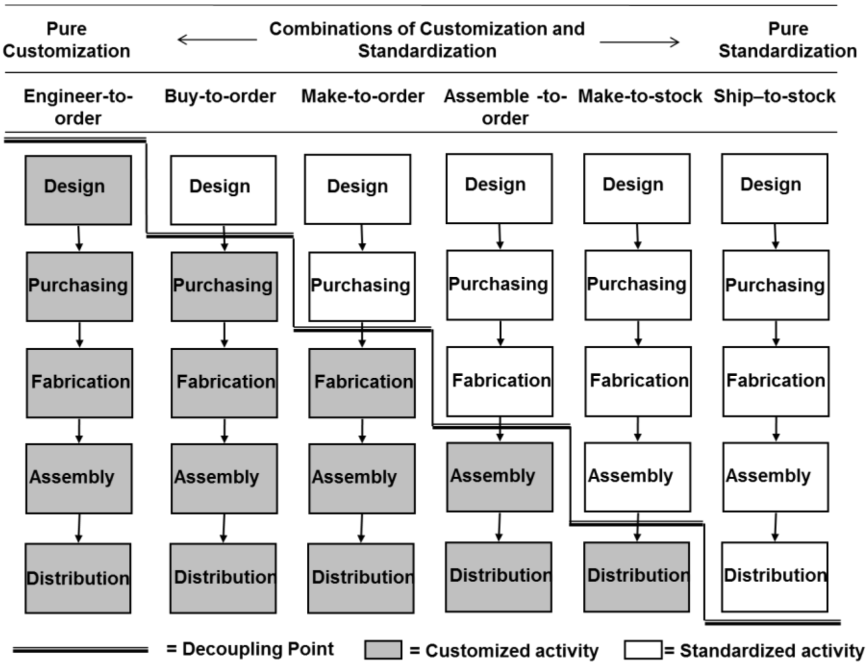


Figure 1: Continuum of logistics types (Gosling et al. 2017)

Viewing construction through this theoretical lens affords some reflection on the underlying characteristics of ETO supply chains, as well as a contingency based reasoning for 'what is appropriate'. ETO types generate customised products, often as 'one-offs' (low volume, high variety per unit of products) (Hayes and Wheelright, 1979), resulting from unique project-based, temporary multi-firm supply chains (Artto and Turkulainen, 2018), having higher degrees of risk associated with requirements uncertainty, customisation capability and longer lead-times. This opens the possibility to compare and contrast variations of underlying characteristics and management approaches across sectors that share ETO attributes, for example in shipbuilding (Semini et al., 2014) and capital goods (Cannas et al., 2019). While such work brings value to sub-sectors of the construction industry, for example, in house building (Barlow et al., 2003, Barker and Naim, 2008) as well as ETO more generally, particularly at a component level or elements of routine work, its adoption must be mindful.

The foregoing discussion highlights where more conventional thinking has a place, and where new and different thinking is needed. These characteristics call for the adoption of distinct construction ETO approaches so as not to run over planned time and budget. Yet, often, we find an assumption that the contextual environment is ordered. For example, as with the predominance of the translation of 'lean' techniques (e.g. Tezel et al., 2017). As Flyvberg et al. (2003, p. 73) noted,

"too many…. studies…. of megaprojects assume projects to exist in a predictable Newtonian world of cause and effect where things go according to plan. In reality…things happen only with a certain probability and rarely turn out as originally intended."

Embracing such assumptions, the Cynefin phenomenological framework (Kurtz and Snowden, 2003, Snowden and Boone, 2007), which we refer to simply as Cynefin, provides a classification that allows understanding of the 'habitat', or 'cynefin' in Welsh, within which the project is perceived to exist (Denicol et al., 2020). Figure 2 shows its domains. Cynefin classifies contexts that we may find ourselves in, in terms of ordered, Simple and Complicated, and unordered, Complex and Chaos. These domains have very different characteristics, especially in terms of the assumptions about the nature of cause and effect, and so it is evident that different managerial approaches are needed.

A key message is that management methods or styles are not so much 'wrong' as 'wrong for their domain', so identification of the domain becomes critical for success. In order to determine which domain we are 'in', the implication of which is to give a basis for agreement on the appropriate management methods and styles, usually requires an element of discussion, discourse and ultimately agreement or consensus among different stakeholders. Hence, we may actually find ourselves in a fifth Disorder domain, where there is no shared understanding of which of the other four domains we are in.

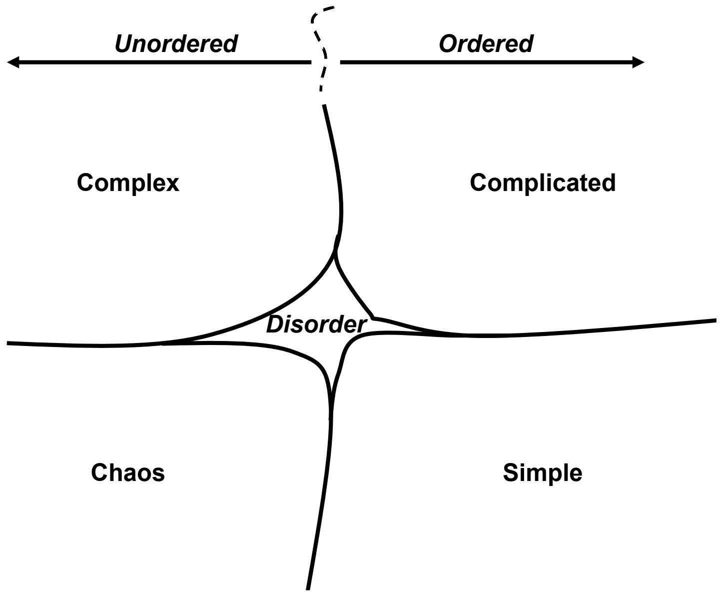


Figure 2: The Cynefin domains (Snowden and Boone, 2007, Kurtz and Snowden, 2003)

Given the multifaceted nature of complex projects, it is logical that we question the tendency to 'force' the same form of managerial interventions as found in ordered environments onto them as a 'one size fits all'. Cynefin, which was originally developed in the knowledge management discipline, has travelled in other fields of endeavour. This includes healthcare, where Fulop and Mark (2013) argue the need to embrace Disorder as a starting point for discourse, allowing leaders to then make sense of which domain they are in. Vollmar et al. (2017) also apply the ideas in engineering production, exploiting Cynefin to categorise different types of engineering design approaches arguing for different processes and people skills for each.

## 3. ETO supply chains and design complexity

Design is not the only determinant of complexity, but it is a good aspect of production practice to use to illustrate how the Cynefin domains can be used. Similar mapping can be undertaken, for example, regarding stakeholder influences, weather, legislation and so forth. Unlike build-to-order through to ship-to-stock systems, where engineering design is part of a separate new product introduction process, engineering design is an inherent phase of the overall project process in construction, and ETO more generally (Dallasega and Rauch, 2017). The design especially as it drives the subsequent behaviours and performances of complex ETO project-based supply chains especially in construction (Barker et al., 2004, Salet et al., 2013), needing a concurrent engineering approach requiring a multidisciplinary team, with members from the various phases, to collaborate to ensure the phases are all aligned.

In considering engineering design, Gosling et al. (2017) propose three main categories of ETO types for construction projects; Existing Designs, Codes and Standards, and Research, as shown in Figure 3. They motivated their study from the perspective of project complexity, uncertainty, risk and mitigation approaches, such as through varying contractual arrangements and/or degrees of innovation.

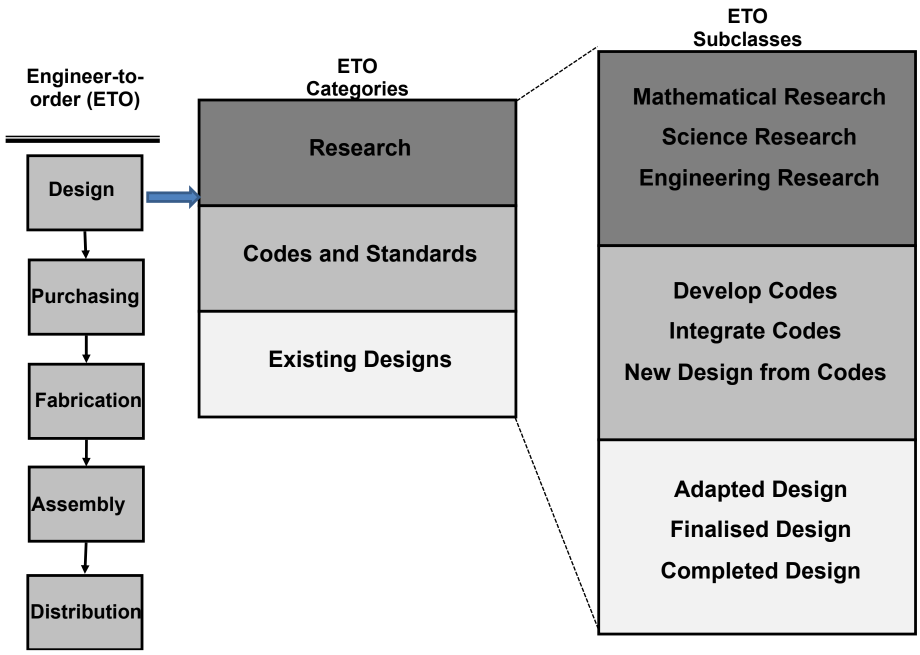


Figure 3: Refining and unpacking the engineer-to-order supply chain (Gosling et al. 2017)

In Existing Designs, previous designs from other projects will be available 'in-stock' to be utilised 'as-is'. Here we find low levels of uncertainty and standard solutions offered to clients. What constitutes 'as is' is not without design consideration, however, and so remains an ETO project. This is because the suitability of any solution must be reviewed against the proposed application (the review is a matter of 'design') and, in any case, the construction environment between two otherwise identical projects will vary in location and timing, even if a previously Completed Design is copied exactly. It is recognised, also, that when existing designs are 'copied', change is often introduced: for instance in Finalised Designs the 'Existing Design' would be stretched or modified in some way to prescribed rules, or for Adapted Design the design solution is an adaptation of the pre-existing design but is constrained to comply with all the design characteristics of the original. A risk for suppliers is that their 'products' get superseded in the marketplace so clients find that existing designs do not provide optimal solutions to their specific requirements and turn to competitors.

In Codes and Standards, designs are developed from formal codes of practice exemplified by British Standards, Eurocode guidelines or those published by institutes such as the American Concrete Institute. A new design would result from using established codes, standards and principles to develop new designs. Alternatively, the design is a result of the development of new codes integrated with established codes, or new codes are established based on engineering research. Hence, in 'codes and standards' the level of uncertainty is higher when compared to 'existing designs' so that there is some innovation required to exploit existing engineering research and/or codes and standards. The risk here is that new designs lead to higher costs and lead-times in exploring alternative solutions.

Within the Research category, designs require fundamental research or research development to be undertaken on a 'to-order' basis. Engineering research may be required, such as the testing of materials, principles or applications, or science research may be undertaken, where the theoretical grounding may exist but the application is uncertain. Where the theoretical principles are unclear or may not exist then some form of fundamental mathematics or science based research will have to be undertaken, for example, advances in material science (e.g. the development of 'intelligent concrete', or the evolution of some new character of the finite element method). In this category we will find the highest degree of uncertainty to moving predictably from initial statement of need through to outcome, and there is a risk that the solution does not perform as intended or that is it is not even possible to realise the solution.

**4. Cynefin and ETO project-based construction supply chains**

Kurst and Snowden (2003) and Snowden and Boone (2007) give a comprehensive description of the different domains in the Cynefin framework. Based on their descriptions we can give a brief precis of each before giving examples of its consideration in construction and supply chain management.

In the Simple domain, cause and effect relationships are easily understood and statically modelled, it is easy to predict the future. There is a dominance of standard operating procedures and benchmarking to determine best practices. Managers will exploit sense making, use standard classification techniques and then determine appropriate responses to events.

For the Complicated domain, cause and effect is clearly visible and forecastable, but the sources and sinks of events are separated by time and space. Managers still exploit sensing strategies, evaluating and assessing gathered data, and determine responses for exploitation in readily predictable scenarios.

Cause and effect behaviours and patterns in the Complex domain are only apparent 'after the event' and there is no perfect repetition. Classic quantitative/systematic approaches exploited in the ordered domains are not useful here, nor in the Chaos domain. We need to capture different perspectives of the same situation from different stakeholders to probe our environment in order to understand the situation in which we find ourselves, allowing us to better sense and respond to events.

The primary approach in the Chaos domain is crisis management, where actions are undertaken as a reaction to particular events as cause and effect is not discernible and there is no time to analyse. The modus operandi is to act first, then sense the outcomes of actions in order to determine appropriate next-step responses. The Chaos domain may be undesirable, say, due to a catastrophic failure, or it may be created in order to instigate innovation or change.

The fifth domain is Disorder. Herein is the space where there is a need to find consensus as to which of the other four domains we should consider ourselves to be in. So, in a multi-firm project-based supply chain, we could find that those team members who have a propensity for the tools and techniques of one of the other four domains may wish to push an agenda that satisfies their 'comfort zone'. We may then find ourselves either in a continuing discourse between team members and the job does not get done, or one of the members dominates and we end up with a management methodology that is not right for the job at hand with potentially dangerous outcomes.

To some Disorder may sound the same as Chaos. Kurst and Snowden (2003) draw a clear distinction. "In chaotic space, we can assume that all connections have been broken, that possibility reigns, that old patterns have been disrupted, and that the outcome is not predictable. In the space of disorder, we know something very valuable – that we do not know. We need to gain more understanding (in every way possible) so that we can find patterns and react to them." Fulop and Mark (2013) also treat the Disorder domain positively, but do point to the need for quite specific management techniques which appeal to diversity, multi-ontology sensemaking and the needs for collaboration and negotiated consensus.

Cynefin has found some traction in construction and ETO project-based supply chain spaces, although rigorous, detailed and empirically based research is sparse. Koskela and Kagioglou (2005) give an exposé of Cynefin and espouse its relevance for the construction sector as a whole and, in passing, indicate the potential of the Last Planner® tool, a production planning system, "to bring the process to the [simple] domain" while acknowledging that, before doing so, there is a need to explore the environment that a project may finds itself. Interestingly, Koskela and Kagioglou (2005), make no mention of the Disorder domain.

Also related to construction, Rooke et al. (2007) again make the assertion that the aim of exploiting Cynefin is to understand which domain you are currently in but then to enforce a form of order. Similarly, Tommelein (2015) promotes lean principles to drive all situations into or remain in the Simple domain. This is a sentiment with which Fulop and Mark (2013) would clearly disagree.

In the general ETO discipline, a notable contribution by Vollmar et al. (2017), relays their experience of applying Cynefin in Siemens AG with inputs from engineers in the energy generation, energy transmission and high-speed train sectors.

While ignoring the Disorder domain, Vollmar et al. (2017) usefully translate the Cynefin framework domains into four engineering scenarios,

*Easy Engineering = Simple;* engineering here exploits existing standardised designs and may include some simple and limited adaptations of existing solutions. This scenario works on repeatable processes dealing with limited complexity.

*Perfect Engineering = Complicated;* the focus is on the delivery of large-scale projects, requiring integration of existing technological solutions with the aim of achieving 'optimum' solutions for the whole life-cycle of the artefact being delivered. There is a heavy reliance on engineers' experiences.

*Pioneer Engineering* = *Complex;* this scenario is associated with a high degree of complexity involving implementation of 'first-of-a-kind' projects, defined as any aspect of the project that is new e.g. the client, brief or technological requirements.

*Crisis Engineering = Chaos;* this is presented as an undesirable state requiring a set of skills to cope with serious situations.

Vollmar et al. (2017) conclude that there is the danger that most ETO companies in Europe work on the assumption that only 'Easy Engineering' exists. Hence, complexity and unexpected events cause considerable disruption because the coping mechanisms do not exist via 'Easy Engineering' approaches, a conclusion that aligns with the thinking in Fulop and Mark (2013). We note that, in seeking 'to bring the process to the [simple] domain', Koskela and Kagiolou (2005), Rooke et al (2007) and Tommelein (2015) would appear to fall prey to the danger Vollmar et al. (2017) warn of.

## 5. Critique and Conceptual Mapping

Vollmar et al.'s (2017) scenarios has some analogue with our perspective of Cynefin and synergy with the ETO categories of Gosling et al. (2017). The notion that 'one-size-fits-all' creates performance and commercial dangers is particularly apposite.

Returning to our illustration of how design can drive complexity, we believe there is a mapping of Gosling et al's. (2017) ETO Design categories of Figure 3 with Cynefin in Figure 2, and hence with Vollmar et al.'s scenarios;

- Existing Designs may be seen as in the Simple domain, where we utilise, or slightly adapt, as in 'Easy Engineering', existing designs to deliver the client brief. This category may be applied also to individual components within a more complex design. There needs to be a high level of certainty and few in situ construction activities will fall into this category, unless they are within a short time period, involve few supply chain stakeholders, and the project-based supply chains follow standardised processes perfectly planned and carefully resourced.

- In Codes and Standards there is similarity with Perfect Engineering's 'optimum' integrated solutions development based on engineering experience, which has analogue with developing design based on codes and practices, which is a collection of engineering know-how. A caveat, however, is that the operational supply chain environment, although still project-based, needs to be fixed, for instance within a factory enclosure, or for construction, where weather and other variables can either be predicted or will have little impact. We do not actually believe that 'Perfect' is entirely appropriate but, in line with the Cynefin 'Complicated' terminology, here we could define the domain as 'perfectible', that is, where a striving to plan every detail, and thereby achieve a mechanistic perfection is both realistic and worthwhile.

- The Pioneering description, where 'first-of-a-kind' solutions are derived is in line in part with our Codes and Standards category, in this case where the operational environment brings considerable uncertainty, and overlaps with our Research category, where a particular situation warrants innovation or starting from first principles or the development of experimental testing to deal with situations that are totally new or have not been encountered before. In reality, much of construction are pioneering, or 'first –of-a-kind', ETO projected-based supply chains in that the physical location, weather, supply chain (including clients, contractors, suppliers, people involved), budget, form of contract or other potential variable will be significantly different from what has gone before.

- The Chaos description one hopes would be encountered only fleetingly and might result from the manifestation of an unexpected outcome or low frequency high impact risk, for instance, or from more creative sources, of which more later.

While we find a good correlation between Vollmar et al's. (2017) use of the Cynefin and our own, it is worth dwelling on some differences. Firstly, Vollmar et al. (2017) place large complex projects within the Perfect Engineering scenario, whereas our experience is that ETO categories find relevance in all of the Cynefin domains. Secondly, Vollmar et al.'s (2017) scenarios describe system 'states', which is a danger in itself, as Kurtz and Snowden (2003) point to, as Cynefin is a perception-based framework, not a definition of state. Perhaps when Vollmar et al. (2017) talk of Siemen AG's industry sectors they do so from the manufacturing aspects of the machinery rather than construction; in civil engineering the operating environment, for many reasons, contains uncertainty. Indeed, this might explain why major programmes, such as transport metros or rail projects, can struggle as there is a cultural clash between Perfect (or Perfectible) Engineering, which is an expectation in the manufacturing engineers' production domain, and Pioneering Engineering, where civil engineers see themselves as residing. It is noteworthy that Crossrail's 2018 re-forecast of end date was apparently due to unforeseeable events in the manufacturing engineering sectors (Gardiner, 2019), which are generally less accustomed to the unexpected than civil engineering and consequently less well constituted to cope – hence the impact is bigger.

We believe the disciplinary boundaries are a prominent theme in infrastructure projects (e.g. Barsam et al., 2017), where the various professional institutions, trades, and industry bodies have developed different traditions and worldviews over long time periods. For instance, in cases where a 'new guard' may think the project should be 'perfectible' and espouse the latest ideas from manufacturing, an 'old guard' may defend a more traditional 'pioneering' viewpoint and espouse the associated management techniques; this can lead to significant clashes and waste or, as in the case of Edinburgh Schools (Cole, 2017) where supervision of brickwork was considered unnecessarily costly, led to highly dangerous, physical disaster.

As we previously noted, Vollmar et al. (2017) step around Crisis Engineering and seem not to embrace it as something that can be done much about. In line with Kurtz and Snowden (2003), we disagree. There is much that can be done to set up supply chain systems for resilience, including early warning, be ready with reactions, prepare the team to keep positive and focussed, prepare people to be self-sufficient, and set clear guidelines to support dispersed decision making. Indeed, some have described construction work as 'organised chaos' (Sullivan et al., 2011), in which minor crises are resolved on a daily basis. The point we are making here is that there is nothing wrong with this approach. As Weick and Sutcliffe (2007) point out, in some cases dispersed decision-making is what brings efficiency, safety and successful outcomes. Weick and Sutcliffe (2007) also point out that assurance with dispersed decision-making calls for great organisational maturity.

Through the Cynefin approach, we recognise that complexity and chaos can be inevitable in the natural and multi-stakeholder supply chains of major infrastructure construction, and make the point that to recognise this and act accordingly is the key to containing chaos and avoiding unnecessarily being in the Disorder domain. There are situations where outcomes that are difficult to foresee arise. For example, in the early 2000's Jubilee Line Extension on the London Underground, the business case was founded on a particular form of line signalling being effective, but it was not possible (Watt, 2001). This solution had to be abandoned and a new solution with less capacity adopted.

It is worth thinking also that we may wish to create a situation where we instigate chaos, possibly as a way to drive change and innovation. Well adapted organisations will react positively and end up 'Thriving on Chaos' (Peters, 1989). Other examples of where chaos might have positive uses are where there are definite end goals but there is rightly an expectation that the course of action will need radical re-thinking, and we need to get the team out of its comfort zone. Another example is where a project is reliant on genuine research, by which we mean that the findings are not foreseeable and could be highly variable; for instance, where a new type of solution is envisaged, but the new solution relies on a new technology which is yet to be proven, a completely different solution would need to be envisaged if the specific new technology did not work.

We also note that, of the construction and ETO papers we cite that refer to Cynefin, none embraces the central Disorder domain. We believe this is an omission and, in agreement with Fulop and Mark (2013) in their research in leadership in healthcare, we should heartily embrace the central zone and see it as a point of particular value in the Cynefin. On an ETO project, if different parties disagree on the domain, there is a need to recognise this and accept that we are in the Disorder domain. The role of leadership now becomes to find consensus as to which of the four main domains we adopt as the 'habitat' for the project. A failure to recognise and properly work through Disorder, will leave the project with misunderstandings, short on teamwork, and with conflict and demotivation: in short, a disaster and, in our view, worse than being in the 'wrong' domain provided there is consensus. Perhaps a pertinent example is the recent situation with Crossrail in the UK, where, due to systems integration issues, the project was on the cusp of Disorder. Tensions, pressures and disagreements called for consensus building to determine the appropriate domain, and hence solution (Horgan, 2019).

## 6. Cynefin for complex project-based supply chains

Relating examples to the domains of the Cynefin requires some care, requiring consideration of both work content and of the variables that influence it. Issues such as, location, regulations and legal frameworks, supply chain, weather conditions, what risks manifest and which do not, client requirements, third party stakeholders, scale and interdependency of different elements, unexpected as-found conditions or lack of success with experimentation and innovation all have a bearing; the list could go on. Add to this that all of these factors may change with time; for instance the client team might be substituted during a project and the new team bring a new interpretation, or neighbours might change their attitudes once they become aware of 'just what is going on over the hoarding'. A lot also derives from experience: a senior professional will know how to plan for uncertainty, even chaos, and keep their effects confined or even treat them positively; an inexperienced person is less likely to have the speed of reaction and pre-prepared contingencies that prevent perturbations becoming instabilities.

Based on our interpretation of the Cynefin domains, they relate to complex ETO project-based supply chain and construction management approaches in the following ways:

*Simple/Easy:* examples might be speculative build housing or retail parks, and then only when not significantly at risk from uncontrollable factors such as market forces, geology, weather. Designs must be completely determinate and the workscope place little reliance on the interaction between groups with differing objectives. For more complex projects the domain can have relevance only at component level. In the Simple / Easy domain we will find repeatability of designs with maybe variations to accommodate local circumstances e.g. external cladding to fulfil planning regulations – it would be critical, however, that any local adaptation is fully detailed. There is the expectation that standard operating procedures govern the project management approach, exploiting various tools such as program evaluation and review technique (PERT) or critical path analysis (CPA). Hence, we ensure certainty of quality, time and cost, making sure people strive for a mechanistic perfection, have thoroughly thought things through, spending time and money on prototyping, developing highly detailed engineering specifications, and enhancing efficient 'lean' techniques. This domain is fragile however. For instance, a specific supplier might go out of business, exchange rates or import constraints might vary. Unless we are prepared, the 'simple and easy' suddenly becomes chaos.

*Complicated/Perfectible:* An example might be the erection of a single span bridge of simple design, where the influencing variables show change but there is a perception that they are manageable and perfectible, and a perfect plan *can be,* and importantly, *should be* formulated and enacted. In such a case, we still remain in an ordered domain and the problem at hand may be mastered, for instance, by comprehensive briefing, a well-investigated geology and a client who uses a well understood and standardised specification. Management here may utilise scenario planning, coupled with a traditional risk register, exploiting the project team's expert opinions to determine a number of different feasible designs for the client and highlighting potential hazards.

*Complex/Pioneering:* An example here would be first of a kind work such as a London Rail Terminus rebuild, which includes multiple influences and stages of work, many stakeholders, and a long and protracted duration. Here, we find the influencing factors are more unpredictable than in previous domains. Management techniques are to develop a robust plan with an emphasis on re-evaluation, renegotiation and responsiveness to changing circumstances to retain the smooth progress of the project as a whole, within which a big picture perspective causes detailed plans to focus on key objectives. The management approach will be to establish a multidisciplinary integrated project team to ensure the breadth and depth of stakeholder involvement. Typically, the project team tends to involve 'experts' from different supply chain firms but will seek diversity of opinion to ensure that all stakeholder perspectives are represented in decision-making; the focus is on people, to build collaboration and trust. There is far less emphasis on immediate costs and there needs to be flexibility regarding budgets. The New Engineering Contract Option C (NEC, 2017) and Project 13 (ICE, 2018) enshrine this idea. The seeming paradox that a focus on cost reduction drives cost up is explained by considering how short-term cost reduction undermines the ability of the team to respond to the emerging complexity; short term costs should be seen as investment, that will yield their return in due time: no investment, no return and we are poorer for it. Codified and procedural management approaches are inappropriate, instead a richer understanding is needed; "narrative techniques are particularly powerful in this space" (Kurtz and Snowden, 2003).

*Chaos/Crisis Engineering:* We envisage many types of scenario, but in all cases the project needs to transform from Chaos into a more stable domain as rapidly as it can. In the safety realm, the Bow-tie approach (Zhang and Guan, 2018) gives equal weight to avoiding crisis as it does to managing the outcome; this approach is used where it is simply uneconomic (the project would not proceed) to plan to avoid every conceivable negative outcome. In cases of structural collapse or earthquake for instance, immediate life safety is the priority and all else must cease. A second type of scenario is where a single 'project', or 'contract', within a broader programme, suffers a radical change of priorities as a consequence of the changing climate in the whole programme. For instance, on a long metro system, each station starts as its own contract; in time opening the railway becomes the priority and the individual project priorities are subsumed. If a Project Manager for the individual station is less than perfectly briefed, this can be hugely chaotic when viewed from the Project Manager's perspective. In this scenario we need to build in resilience, so that the team is ready for disturbance, and can respond and recover. In another scenario there may be a small part of the project which becomes chaotic: perhaps an area of historic fabric is found to be unstable and cannot be incorporated into the final design as envisaged, needing a review both technically and with planning authorities. The strategy now is to box off this chaotic element, isolate a dedicated team to deal with it, and ensure good order is maintained elsewhere.

We also propose that there are positive scenarios in the Chaos domain, leading to a possible stimulus for innovation. An example from Gosling et al. (2017) involved the development of a new technique for manufacturing large optics. A project team were commissioned to undertake a feasibility study to provide the mirror components for a large-scale telescope. The project made use of developments in nanotechnology to polish to extremely well-defined tolerances. The experimentation encountered set-backs, requiring full re-evaluation of the techniques to be used – a chaotic situation to be in. However, this had been anticipated in the team selection and the commercial and human factors management; the set-backs were seen as opportunities for creativity, so to external observers at least, the project could be seen to be residing in the Complex/Pioneering domain. This idea is enshrined in the idea of 'agile' development, as opposed to 'waterfall'.

Our analysis above has very much focussed on the engineering design element of an ETO project-based supply chain. Similar analyses can be undertaken for any complex variable, for instance stakeholder intervention, whole supply chain stability, legislative change, market demand and so forth.

## 7. Temporality and hierarchy – a case study

Two significant issues that arise from the application of the Cynefin domains in construction are temporality (i.e. when do the domains apply) and hierarchy (i.e. at what level do they apply). As a caveat, the appropriate domain is likely a function of component and timescale – a Complex ETO project, like a live rail terminus rebuild, might be Pioneering/Complex as a whole, but will have aspects which are Easy/Simple, Perfect/Complicated and Crisis/Chaos in parts and in time. While 'a part' in this context might be defined against certain criteria, as for example a system hierarchy wherein a part is a constituent of a whole, it amounts to an aspect of an ETO project-based supply chain to which a specific, rather than generalised, management technique is appropriate. Our point is that a wide range of approaches and attitudes are likely to be needed even in a single ETO project.

We illustrate the merits of thinking across temporality and hierarchy by reference to a well-reported incident – that of the collapse of the outer leaf (external face) of a cavity wall at Oxgangs Primary School in Edinburgh in January 2016 (the 'Edinburgh Schools case'). The incident led to a public enquiry and comprehensive report (Cole, 2017), that considered various technological, attitudinal and process (Towill, 2001) aspects leading up to the collapse, the incident itself and the response, including due considering of the public private partnership (PPP) supply chain and its governance. The collapse had certain immediate local effects, but led to widespread re-construction and disruption, and following the public inquiry report (Cole, 2017) a reconsideration of procurement and professionalism in the building profession generally (Hunter and Young, 2018, Alexander et al., 2019, Love and Mathews, 2020, Waugh et al., 2020). The case study also helps to illustrate ways in which the use of the Cynefin domains can aid sensemaking and selection of risk management styles.

Our previous reflections have focussed on the distinguishing stage of the ETO form of construction project, namely the design stage. The data presented by Cole (2017), however, allows us to consider the Edinburgh Schools case across the generic temporal phases of ETO as in Figure 2, namely Design, Purchase and Fabrication/Assembly/Distribution, where the latter are combined given the nature of the construction sector where resources converge onto a geographical location. In the construction management discipline these equate to the construction phases of "Planning & design", "Preconstruction" and "Construction" respectively (as in Gosling et al., 2016 and Kagioglou et al., 2000). While the continuum of Figure 2 is not explicit about the in-service operation of the product, in construction there is also due consideration of "Postconstruction", or what we may term as in-service Operation.

We present our analysis in Table 1. *For clarity, please note that this table relates to the design of the walls specifically, the walls being only an element of the building as a whole.* We do not give every activity in the temporal hierarchy but just a number to illustrate the application of the Cynefin domains. We also give some insights gained by relating the activities and outcomes to the Cynefin framework. The extraction of narratives from Cole (2017) is in line with the approach used by other authors in determining the implications of the technical failures evident from the case, such as by Alexander et al. (2019) in their consideration of life cycle analysis in public-private initiatives and Waugh et al. (2020) in determining the impact of outsourcing on safety. While the analysis is limited as it is simply based on our own interpretations and reflections, we believe that there is considerable mileage in refining and extending our general approach, say, via meta-analysis and content analysis using multiple secondary data sources (Rabinovich and Cheo, 2011).

| Acitivity | | Cynefin domain | | | | Supporting report narrative (Cole 2017) | Insight from Cynefin |
|---|---|---|---|---|---|---|---|
| | | Simple | Complicated | Complex | Chaos | | |
| Design | Conceptual design | X, Y | | | | A structural engineer designing the structure of a building is required to consider the stability of masonry wall panels to ensure that they can withstand windloadings arising from wind-speeds and loadings as currently prescribed in British Standard BS EN 1991-1-4: 2005 for use with PD 6697 2010, (BS 6399 applied at the time of the design of the PPP1 schools). Both standards take account of location, topographical exposure and orientation.<br><br>The **standardised design** for the cavity walls in the PPP1 schools consisted of an internal leaf built of 140mm wide blockwork, a 120mm cavity consisting of 70mm wide insulation slabs clipped to the inner face of the inner blockwork leaf and a 50mm wide air space, and an outer leaf of either 102.5mm wide facing brick or 100mm wide blockwork with a rendered finish. | |
| | Detailed design | Y | X | | | | Detailed design is complicated; it is perfectly possible to draw out, or otherwise predetermine all the components, their orientation and positioning, but this takes a lot of time and attention. The procurement of the design aligned to a product which is a commodity. There was a lack of thoroughness. |

| Acitivity | | Cynefin domain | | | | Supporting report narrative (Cole 2017) | Insight from Cynefin |
|---|---|---|---|---|---|---|---|
| | | Simple | Complicated | Complex | Chaos | | |
| Purchase | | Y | | X | Z | Recent changes to models of procurement of public building, driven by a desire for greater efficiency, and an unachievable desire to transfer all risk away from the client, have unfortunately not appreciated the need to build into these models the essential provision of an appropriate level of independent scrutiny.<br><br>Edinburgh Council, in common with probably a significant majority of public sector clients undertaking PPP projects, did not appoint Clerks of Works to provide inspection services on the PPP1 schools.<br><br>The most common method of paying bricklayers [is] based on the number of bricks laid rather than on the time [worked and] appear not to take account of the number, type and complexity of accessories that are required... [this is a] perverse incentive... to encourage the omission of elements providing the essential structural integrity of walls. | Procurement was over-simplified. Masonry construction is complicated, and in uncertain site conditions, can become complex. This was not recognised. |

| Acitivity | | Cynefin domain | | | | Supporting report narrative (Cole 2017) | Insight from Cynefin |
|---|---|---|---|---|---|---|---|
| | | Simple | Complicated | Complex | Chaos | | |
| Fabrication / Assembly / Distribution | Logistics coordination | Y | X | | Z | At the time the sub-contractors were pricing the jobs, that only architects' drawings had been available, as the level of secondary steelwork had not been fully developed and therefore may not have been allowed for in the costs agreed.<br><br>Given the wide extent of failure to incorporate elements of reinforcement and restraint to the brick panels that were shown on engineers' drawings across the PPP1 schools, and the fact that these schools were built by a range of different contractors and subcontractors, it is perhaps appropriate that the construction industry reviews how effectively information is produced, coordinated, presented and communicated to contractors and to tradesmen on site so that there is clarity at all levels as to the precise requirements of the design. | Communication was over-simplified. |
| | Manufacture | X, Y | | | | | Standardised products supplied to standard. No faults found. |
| | Material delivery | | X, Y | | | | Standardised products supplied to standard. No faults found. |

| **Acitivity** | | **Cynefin domain** | | | | **Supporting report narrative** (Cole 2017) | Insight from Cynefin |
|---|---|---|---|---|---|---|---|
| | | Simple | Complicated | Complex | Chaos | | |
| | Construction | Y | X | | Z | ....as in the case of the missing head restraints, the failure to incorporate the specified bed joint reinforcement in accordance with the design, impacted significantly on the capacity of the panels to resist the required levels of wind-loading and undermined the integrity of the structural design of the external walls of the schools.<br><br>The PPP1 Contract contained a requirement for the preparation, provision to the Council and maintenance of as-installed drawings and related documentation. This provision has not been adequately complied with...<br><br>the inner blockwork leaf of the cavity wall had been built prior to the construction of the outer leaf of the wall. | The constraints imposed by the procurement gave no room for the sub-contractors to manage the complexity. Add to this that there was no checking (feedback). |
| Operation | Operational failure | X | | | X | A combination of excessive cavity width, related non-verticality, and incorrectly constructed wall ties has resulted in a cavity wall construction which in many of the ties had insufficient embedment of the wall ties in the outer leaf. This in our view is the primary contributory factor.<br><br>It is the view of the Inquiry that the decision to close Oxgangs School on the day of the collapse was entirely reasonable and appropriate. At this stage the Council did not know the cause of the collapse, other than an assumption that it was related to the strong winds associated with Storm Gertrude. | The prevailing assumptions of simplicity led to the ensuing chaos. |

| | |
|---|---|
| Summary learning point | What should be learnt from Edinburgh Schools is that prevailing assumptions of simplicity, in a complicated or complex domain, should be seen as an early warning of likely disaster. It was a miracle no one was killed. |

Table 1: Prevailing assumptions in the procurement of the external masonry walls in the Edinburgh Schools PPP programme.
*[X - where it should have been, Y - where it was, Z - what was going on unperceived]*

While in reality there may be various precursor and/or parallel activities, such as client briefing, developing a business case, creating various options and seeking planning permission, Table 1 shows Design as the first upstream activity sub divided into “Conceptual design" and "Detailed design", although the terminology may vary, e.g. sometimes referred to as “Scheme Design” and “Engineering Design” (Gray and Hughes, 2001, p.106-109).

The initial and primary focus of the Edinburgh Schools inquiry was the failure of the cavity wall construction. At the most fundamental level the “Conceptual Design” of a cavity wall simply involves a technological solution, determining the primary dimensions and the primary layers of material such as the inner leaf, insulation and the outer (external) leaf wall. “Detailed design” will give more information, extending to all details and dimensions, with focus on exact specifications of the various materials to be used and how details are to be provided at all non-standard locations. At this stage there will also be a process element to include requirements for fixings and supplier quality requirements. From an ETO perspective, as the cavity wall element is a standardised design, it would be categorised, from the perspective of design and engineering, as “Existing Designs” and very much in the Simple Cynefin domain. Our narrative will now explore whether this categorisation remains appropriate for subsequent phases of the project – e.g. Purchase, Fabrication / Assembly / Distribution and Operation.

For the Purchase phase we highlight the mobilisation of the various supply chain stakeholders exploiting a combination of information technology, following standard procedures and requiring the establishment of relationships between people and their organisations. Public Private Partnership procurement procedures for construction projects, of which Edinburgh Schools is a type, suggest that there is a reliance on standard approaches that assume the ability to ensure repeatability of outcomes as in previous PPP projects. However, this is too simplistic, as tendering processes are liable to opportunistic behaviour (Ho and Liu, 2004) resulting in considerable variance from the original specification; a major cause of such variance is due to the lack of design specificity at tender, which triggers a need for post-tender design work; this plays to contractors who can then claim variations (Love and Li, 2000). While such ‘gaming’ could potentially categorise the system as in the Complex domain, potentially tipping into Chaos, it seems that the supply chain procurers, namely the client, continued to act on the principle that the masonry wall procurement and execution remained Simple – in effect being a commodity to buy on price with no risk of falling short on meeting the specification. An assumption on behalf of the client that the masonry wall packages were complicated or complex would have led to the client checking what was happening as in Complicated achieving good outputs needs high skill levels, and in Complex outputs are not mechanistically linked to inputs in any case. Had they recognised the Complicated or Complex domain, they would surely have made arrangement to check outputs, in the one case to check skill levels were as anticipated and the nuances of the work appreciated, in the other simply to check that outputs were resulting as wanted. This could have been achieved by, for instance, employing a Clerk of Works, or equivalent such as a resident engineer. Cole clearly recommends this (Cole, 2017).

We show the Fabrication / Assembly / Distribution phase as multi-tiered. Overall, the coordination and synchronisation of the whole supply chain logistics, in terms of people, materials and equipment, has a technological element, for example, real-time tracking and tracing of goods throughout the supply chain, requires collaboration among the various stakeholders to endeavour to follow the established project plan (Sundquist et al., 2018). Again, we indicate the overall execution as being Complex but show that the sub-elements, with three examples given, are a combination of Simple and Complicated, either following standard operating procedures for manufacture or construction, or have an element of time dependency for example, due to vehicle rescheduling and/or rerouting to avoid congestion (Zhang et al., 2016). Cole (2017) does not note any issues prevailing in the manufacture or delivery of goods and materials that impacted on the outer leaf wall collapse. Key issues were in the overall coordination of the supply chain, with a lack of information transparency, with resulting ‘gaming’ as previously mentioned. Although the `construction of the cavity wall itself should be regarded as Simple, two key factors highlighted by the report that contributed to the deviation from standards were the lack of a 'lean' visualisation tool (e.g. see Kattman et al., 2012) by which the brick layers could have determined the depth at which the ties were set into the leaves and the payment mechanism for the brick layers (Cole, 2017).

We complete our synthesis with the postconstruction phase of the project. Here we show initially two temporal states of the same phase, both occurring on the morning of the collapse. The first is of Chaos in the immediate aftermath of the collapse: what are the implications of the collapsed wall, what do we do? The second follows the rapid intervention by the City of Edinburgh Council, who closed the School, which then transitioned the situation (at least so far as the authorities were concerned) into the Simple domain. There then followed an interesting period which we assess as being of Disorder during which there was no consensus on the severity and urgency of the situation. During this period the School remained in use, but subject to expert structural monitoring and a constant weather watch (a Complex arrangement to structural engineers, Chaotic to teachers who had to work around these unsatisfactory arrangements, Simple to pupils (the school was open, get on with it and do as you're told), and Complex going on Chaotic to contractors who had to recognise they had a problem with unforeseeable potential outcomes; meanwhile the City Council, School Governors and staff, contractors and structural advisors sought consensus on what to do and how, constantly abated by parents and the press). Ultimately there followed a phase which began as Complex but later became Complicated during which Oxgangs and the 16 other schools within the same PPP programme were investigated, closed or partially closed, and remediated; this continued until August 2016. Accomplishing this involved bussing pupils to different locations and redeploying staff accordingly – an exercise of immense complexity, likened to a military operation.

## 8. Conclusion – a manifesto for change

We do not regard the Cyenfin as a panacea for sense making in ETO supply chain management. While we commend its principles to our community, we believe there is still much research to be done in terms of determining the extent to which the underlying principles it promulgates in terms of sense-making and managerial interventions, can be executed in our industry. Also, while the Cynefin has travelled from the knowledge management discipline, we believe that it can also form a template for determining the relevance of other idea travels principally from non-ETO manufacturing, where lean thinking has dominated the discourse for an extended period of time. The framework does highlight the need for a range of tools and techniques to support decision making under different circumstances, some of which must embrace uncertainty and complexity.

An important implication flowing from the application of Cynefin is the demonstration of need for supply chain management professionals to put themselves in a position to look at situations with an appreciate of complexity, perspective and ability to determine what is right for the circumstances. When observing those who have a good grasp of this, some may attribute this to intuition. However, we contend that it requires a sophisticated combination of attitudinal, process and technological change. In terms of attitudinal change, the concentrated effort to develop mental models through continuing professional development and exposure to frameworks such as Cynefin, would support a broader worldview and the formation of heuristics or 'rules of thumb' to enable decision making in different situations. It is our hope that this would promote sensitivity for where and when tools and techniques can and should be applied, an appreciation of the limitations of certain approaches and responses, and a willingness to facilitate accommodation of worldviews. Processes and technology can also play a supporting role by supporting human centred interactions, multi-disciplinary working, and new conception of risk based around complexity.

Our brief analysis of the Edinburgh Schools case indicates that any prevailing assumption of simplicity, as evidenced by the adopted management techniques in procurement, in a Complicated or Complex domain, can lead to chaos and has potential for disastrous outcomes. We believe that here is a need for further consideration of the management techniques aligned with each domain, especially if the ETO project is in the Disorder zone. In the latter case, stopping the job to get alignment of thought, or at any rate acceptance of the legitimacy of different perspectives, is probably the right action. The management approach to Disorder will likely be in the form of conciliation and arbitration, either achieving consensus or agreeing to disagree through the accommodation of worldviews. But as we have seen from our interpretation of the Edinburgh Schools, while there are instances when it is legitimate to be in Disorder, we need to find ways of facilitating high velocity sense making, domain recognition, determining journeys between domains and action taking, involving all relevant stakeholders – including project teams, their supply chains, communities and regulators. Hence, we believe there is further research required by the supply chain management community to further this endeavour, which will require a multidisciplinary, multimethod approach in order to fully embrace the challenges found in each of the five Cynefin domains and/or to extend the Cynefin itself.

A principal area for further research is in risk management, which often determines the primary rules of engagement at the outset of a project by ascertaining what are likely adverse events and how they may be mitigated. We advocate a need for new ways of thinking about risk assessment and de-risking with respect to Complex/Pioneering projects, in which narrative forms guide project teams, who must hear the voices of all stakeholders, and will need to embrace a wide palate of management techniques in response, varying with timeframe, scale (component versus the project as a whole) and what risks manifest, what do not. Existing risk registers are based on simple one-to-one relationships between cause and effect and often miss the interconnectivity between different causes and different effects. Hence, existing risk management approaches, where the assumption is that the project is 'ordered', are susceptible to cross suddenly into the 'chaos' when behaviour deviates from the 'risk register model' norm. We assert that experienced engineering managers recognise that the unexpected occurs from time to time and have pre-prepared strategies to contain any chaos that might ensue; this includes forming strong interpersonal relationships and team resilience, that can be called on in time of need.

In addition, while previous research has suggested the qualitative benefits of Cynefin we have yet to find rigorous and detailed quantitative assessments of its application. Research that applies and evaluates the impact of Cynefin, in terms of quality, cost and time outcomes, will be necessary if organisations and their supply chains are to invest in its ethos.

Finally, we believe that the Cynefin enlightens our thinking. The concept of 'journeys through the Cynefin', as responses are developed and enacted, changing their domain as this happens, in itself gives a narrative which is easily grasped and makes sense of the complex and emergent in a world which seeks efficiency and craves certainty. An underlying feature of our proposition is that while many aspects of construction can be successfully managed as fundamentally orderly, many cannot. A serendipity of Cynefin is that it draws the unorderly aspects of complex projects into an ordered framework that those who wish for an orderly oversight of projects and programmes will take comfort from. Success, however, relies on supply chain managers relaxing their control somewhat and, while they may retain accountability, adopting a role which supports experts and engineering professionals to take the lead. Only in this way will the inherent risks that complexity brings to 'complex projects' be successfully controlled.

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