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Unpacking the Ambiguity of Rework in Construction: Making Sense of the Literature

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Abstract

Rework is a pervasive problem and stymies practice in construction. A considerable amount of research has been undertaken to address rework, but there has been limited progress made in reducing its occurrence and adverse consequences. The use of differing definitions and methods to determine its causes and costs has resulted in a quagmire of interpretations being propagated in the literature. In this paper we review the extant literature and unpack the ambiguity that surrounds the problem of rework. It is suggested that in order to reduce and contain rework then an ameliorated systemic understanding of its causation and consequences is required to engender a benchmarking strategy that can provide organisations with the knowledge and ability to learn and improve their performance.

Keywords: Construction, digitisation, error, learning, quality, productivity, rework, system

1.0 Introduction

> "Learn from yesterday, live for today and hope for tomorrow. The important thing is not to stop questioning"
>
> (Albert Einstein, 1879-1955)

For several decades it has been acknowledged that rework is a major issue in construction projects worldwide (e.g., Hughes, 1951; Atkinson, 1987; Oswald and Burati, 1992; Robinson-Fayek *et al*., 2004; Hwang *et al*., 2014; Taggart *et al*., 2014; Ye *et al*., 2015; Forcada *et al*., 2017). It would, however, be unreasonable to suggest that all projects experience rework. Naturally, the levels of rework that occur in projects will vary significantly, as does its cost and consequences (Love *et al*., 2018a). Despite the considerable amount of research that has been undertaken there has been limited progress made in reducing (i.e. measures designed to limit the occurrence of errors) and containing (i.e. measures designed to enhance the detection and recovery of errors, as well as seeking to minimise their adverse consequences) rework in construction. In this paper we review the extant literature and unpack the ambiguity that surrounds the problem of rework. It is suggested that in order to reduce and contain rework then a systemic understanding of its causation and its consequences is required to engender a benchmarking strategy that can provide organisations with the knowledge and ability to learn and improve their performance.

2.0 Definitions of Rework

Put simply, rework as a verb means to revise or work again. In the context of construction, a plethora of rework definitions have been propagated in the literature centred around the themes of quality (i.e. conformance) and change/deviation (Love *et al*., 2018a). In fact, terms such as quality deviation, quality failure, non-conformance and defect have been used interchangeably to describe the nature of re-doing work (Knocke, 1992; Josephson and Larsson 2001; Mills *et al*., 2009; Aljassmi and Han, 2013).

Ashford (1992) drawing on quality uses the definition of rework provided by BS4778:1987, Part 1, which defines it as "the process by which an item is made to conform to the original requirement by completion or correction" (p.194). Abdul-Rahman (1993) used the term, *cost of non-conformance* as defined in British Standard BS6143: Part 2 (1992) to determine an attribute of rework. Here, non-conformance costs were defined as "the cost of inefficiency within the specified process, i.e., over resourcing of excess, materials and equipment rising from unsatisfactory inputs, errors made, rejected outputs, and various other modes of waste" (p.x). A similar characterisation of rework, based upon the way in which a contractor identified its occurrence in their projects, was presented in Love *et al*.'s (2018a) study where "an action on a non-conforming product to make it conform to requirements" was required.

Using the BS6143: Part 2 (1992) for identifying the costs of quality, or otherwise known as quality costs, Barber *et al*. (2000) defines rework as a 'quality failure', which is a subsection for measuring non-conformance costs. Quality failures are classified as:

- *internal failures* – cost incurred due to scrapping or reworking defective product, or compensation for delays in delivery; and
- *external failures*– cost incurred after the delivery of a product.

Continuing with theme of conformity, the (Australian) Construction Industry Development Agency (CIDA, 1995) defined rework as "doing something a least one extra time due to non-conformance to requirements". Considering both the process and product, Love (2002a) suggested rework to be the "unnecessary effort of re-doing a process or activity that was incorrectly implemented the first time" (p.19). But as research has demonstrated, rework can arise due to requirements from design and construction changes, even though standards or requirements may have been achieved (Davis *et al*., 1989; Burati *et al*., 1992; Willis and Willis, 1996; Love and Li, 2000a). Realistically, design changes and omissions should not be included in the determination of rework. When they are excluded then rework costs tend to be less than +1% of construction costs, and then are attributable to those who are responsible for them (Table 1).

The term quality deviation was coined and used by Farrington, (1987), Davis *et al*. (1989) and Burati *et al*. (1992) to encapsulate rework. In defining a quality deviation, Farrington (1987) refers to changes, errors, and omissions that may occur during design and construction where (p.27):

- "a change is a directed action altering the currently established requirements;
- an error is any item or activity in a system that is performed incorrectly resulting in a deviation; and
- an omission is any part of a system including design, construction, and fabrication, that has been left out resulting in a deviation to the customer (cost of repairs, returns, dealing with complaints and compensation)".

A repair, which is "the process of restoring a non-conforming characteristic to an acceptable condition even though the item may not still conform to the original requirement" (Ashford, 1992; p. 193) can also be included as rework. Adding further clarity Burati *et al*. (1992) defined *quality* as the "conformance to established requirements" and a *deviation* as "changes to the requirements that result in rework, as well as products or results that do not conform to all the specification requirements, but do not require rework" (p.35). The term deviation rather than failure or defect is used here to indicate that a product or result that does not conform to all specification requirements does not necessarily constitute an outright failure. A deviation, therefore, may be classified as an imperfection, non-conformance, or defect based on its severity (Burati *et al*., 1992).

Table 1. Summary of rework costs from key studies undertaken prior to practical completion

Descriptor	**Cost** +	**Sample**	**Measure**	**Inclusion of changes/omissions**	**Type of Study**	**Author**
Non-conformance	10% to 20%	-	Total project cost	No	Theoretical estimate	Cnudde (1991)
	2.5% and 5%	2	Contract value	No	Case study	Abul-Rahman (1993)
	0.39%	345	Contract value	No	Case study	Love *et al*. (2018a)
Quality deviation	12.4%	12	Total project cost	Yes	Case study	Burati *et al*. (1992)
	3.3%	1	Total project cost	Yes	Case study	Willis and Willis (1996)
Quality failure	10%	4	Construction costs	No	Case study	Nylén (1996)
	16% and 20%	2	Contract value	No	Case study	Barber *et al*. (2000)
	0.05%	1	Total project cost	No	Case study	Jaafari and Love (2013)
	0.18%	68	Contract value	No	Case study	Love *et al*. (2018b)
Defect	2.3% to 9.3%	7	Construction costs	No	Case study	Josephson and Hammarlund (1999) †
Rework	5%	1	Contract value	Yes	Case study	Burroughs (1993)
	2.4% and 3.15%	2	Contract value	Yes	Case study	Love and Li (2000a)
	6.4%	161	Contract value	Yes	Questionnaire survey	Love (2002a)
	0.45	14	Contract value††	No	Case study	Love and Li (2000b)
	5%	359	Construction cost††	Yes	Questionnaire survey	Hwang *et al*. (2009)
	2.75%	40	Contract value	No	Case study	Forcada *et al*. (2017)
	3.1% to 6%	114	Contract value	Yes	Questionnaire survey	Yap *et al*. (2017)

† Originally reported findings as 'defects'. Presented the same research in Josephson and Larson (2001) as 'error' and then in Josephson *et al*. (2002) used the term rework

†† No differentiation between contract value and construction costs is made in the literature, though they can have different meanings as additional services may be provided

The description of rework presented by Farrington (1997), Davis *et al*. (1989) and Burati *et al*. (1992) is broad in context and captures issues that emerge from design and are played out in construction and during off-site manufacture. More specifically, Rogge *et al*. (2001) focuses on rework "as activities in the field to be done more than once in the field or activities which remove work previously installed as part of the project". Based on the aforementioned, Robinson-Fayek *et al*. (2004) defined rework as "the total direct cost of re-doing work in the field regardless of the initiating cause", which specifically excludes change orders (variations) and errors caused by off-site manufacture (p.1078).

Noticeably, the scope of rework is affected by the definition that is adopted for a given study. However, when a change order is introduced into the rework equation, contractors will typically be paid for re-doing work. This will form part of a project's cost of rework with change-order cost being invariably borne by a client. (Love *et al*., 2018a). When change-orders are excluded, then rework costs that are incurred are typically borne by the contractor and subcontractors, though there may be instances when designers (i.e. architects and engineers) may be responsible for them as highlighted in Love *et al*. (2018a). Irrespective of the rework description that is adopted, the number of events that occur between contract award and the issue of practical completion will tend to progressively increase (Figure 1).

Prior to the issue of the certificate of practical completion, defects will be typically identified and will require rectification; a process often referred to as *snagging* items (Sommerville *et al*., 2004; Sommerville, 2007; Taggart *et al*., 2014). Such defects are the physical manifestation of an error or omission (Knocke, 1992) and listed for rectification before the certificate of practical completion is issued. Essentially, a defect is a "failing or shortcoming in the function, performance, statutory or user requirements of a building, and might manifest itself within the structure, fabric, services or other facilities of the affected building." (Watt, 1999: p.96). Defects have been classified as being minor or major (Porteous, 1992). According to Porteous (1992) minor defects are those that "arise from poor workmanship or defective materials used in the erection or construction of building, but do not render the building unsafe, inhabitable or unusable for the purposes for which the building was designed or intended" (p.46). A major defect, however, is the exact opposite to those of a minor nature where the building becomes unsafe, inhabitable or unusable.

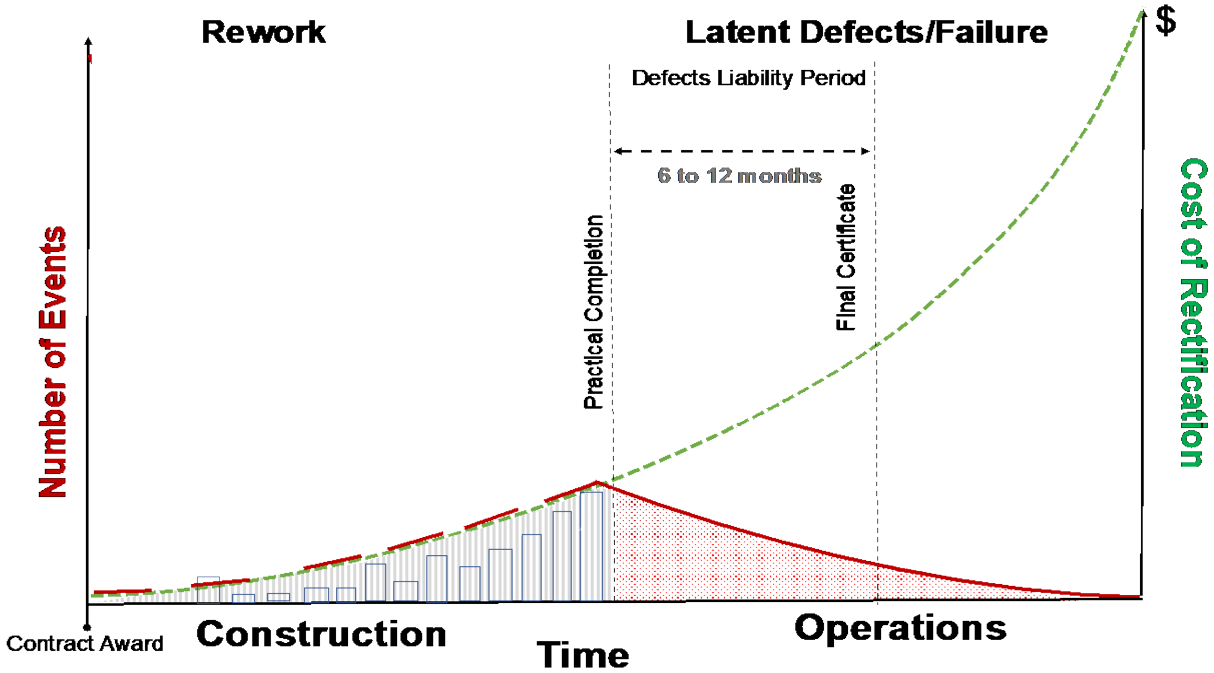


Figure 1. Rework during construction and the operation of an asset

Generally, the rate-of-error that results in defects materialising during the construction process will vary depending on prevailing time constraints and type of work being undertaken. The subcontract trades that have a tendency to significantly contribute to rework costs are often associated with substructure and superstructure, for example, piling, structural steel and concrete works (Love *et al*., 2018a;b). Defects prior to hand-over tend to be of an aesthetic or cosmetic nature (e.g., painting and hardware) and commonly associated with electrical issues, commissioning plant and equipment (Taggart *et al*., 2014). Prior to practical completion, however, an immediate way to reduce and/or eliminate post-handover defects is to ensure that quality controls and inspections are regularly implemented during design and construction.

At this point, it is noteworthy to differentiate between a defect and failure, as these terms have been used interchangeably and within the context of rework when in fact there is an explicit delineation between them. Atkinson (1987) makes this point of difference as "a failure is a departure from good practice, which may or may not be corrected before the building is handed over. A defect, on the other hand, is a shortfall in performance which manifests itself once the building is operational" (p.54). After the issue of the certificate of practical completion, the defects liability period then officially commences. The actual period will vary depending on the nature of the contract; for straightforward building projects it is usually six or 12 months.

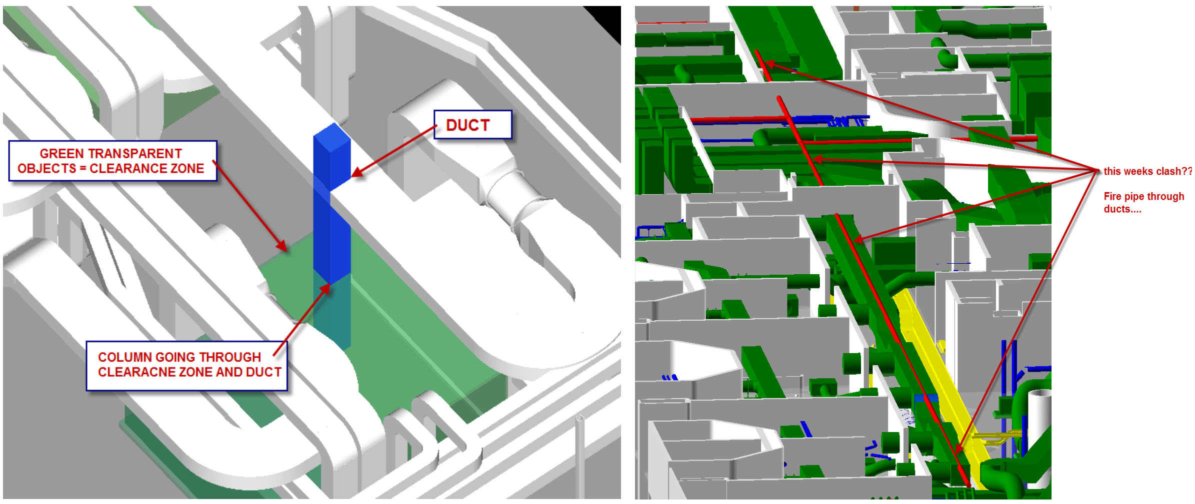
For complex engineering projects such as a power station, it can be as long as 24 or 36 months. Often faults in an asset cannot be reasonably identified prior to practical completion even though a thorough inspection has been undertaken. Such faults are referred to as *latent defects* and once identified will be subject of rework. For construction organisations defects after practical completion can be costly to rectify, not only financially but they can also have a negative impact on their reputation.

Definitions of rework abound in literature. However, the lack of differentiation between the terms used to describe rework can lead to inaccurate and incomplete measurements, cost determination, and possibly inappropriate strategies for reducing and containing its occurrence. Without having a common operational definition in place that can be used to establish a baseline for purposes of benchmarking and understanding the nature of the problem that confronts the construction industry, rework will remain in a miasma of misinterpretations and misunderstandings. If a systematic perspective to rework is adopted and systems knowledge is applied to generate explicit concepts and a common language that can provide scholars and practitioners with the capability to articulate and reflect on its systemic occurrence, then they will be able to address this problem in a considered way.

3.0 Rework Costs

The use of different interpretations of rework has resulted in a piecemeal approach to addressing this problem which has hindered progress to determining its real cost (Love *et al*., 2018b). The corollary is that the reported costs of rework have been found to range from less than +1% of a project's contract value to over +20% as presented in Table 1. Some studies, however, have incorporated the additional cost of design changes and omissions into the calculation of rework costs (e.g., Burati *et al*., 1992; Hwang *et al*., 2009) while others have disregarded them focusing on those occurring purely in construction changes (Abdul-Rahman, 1997; Forcarda *et al*., 2017). The costs borne by the contractor during construction, where possible, are then *back* or *contra charged* to subcontractors or even to designers (e.g. architects and engineers), but this is an issue that has been overlooked when reporting costs in most rework studies. The reported rework figures would have been significantly greater if the indirect costs that materialise from delays, disruption, claims and litigation were also included. Such indirect costs are difficult, sometimes impossible, to quantify in monetary terms. Notably, Love (2002b) estimated that the cost of rectifying a poor-quality work can be more than six times its original cost. Additionally, Love (2002a) solicited industry experts estimates of indirect costs and revealed them to be, on average, +5.6% of contract value.

Despite the ambiguity surrounding rework costs, it is suggested that the reported figures should be treated with caution. In fact, there is a danger that they have become an unverifiable factoid as no context or *caveats* are provided when they are cited. For example, *BuildingPoint*, an authorised dealer of Trimble software products (BuildingPoint, 2016) quoting Love *et al*. (2004) state that rework costs are 12% of a contract's value. In doing so, limited attention is provided to the context of the research, as to how this figure was derived and how costs were apportioned. Then BuildingPoint (2016) suggest that creating a building information model (BIM) improves constructability and reduces the primary costs of rework that can materialise on-site due to clashes and errors (Figure 2). Indeed, the creation of a BIM may enable the visualisation of clashes and identify errors, but there is no empirical evidence to demonstrate that it reduces rework during construction, particularly its underlying causes that have been identified to be associated with managerial actions and organisational decision-making (Love *et al*., 2018c;d).



(Source: Love *et al*., 2013)

Figure 2. Example of clash detection for ductwork

Notably, clash detection is as only as good as the model that it is based on, information contained within it and the *rule sets* that are defined to identify the clashes. In the case of BuildingPoint (2016), it is evident that they are simply trying to suggest that their software products will reduce rework and significantly improve an organisation's revenue. Immediately several questions come to mind which include: What organisations are BuildingPoint referring to? How and by what amount do they expect revenues to increase? There is a danger that if reported rework figures are taken out of context and used to promote a misleading agenda, then misleading factoids can emerge. If construction projects are experiencing +12% rework costs, and design changes are the major cause, then contractors' revenues would increase as they make additional profit from undertaking additional works over and above what they have been contracted to undertake (these are change orders which are not the responsibility of the contractor).

There have been several studies that have examined the causes of latent defects (e.g., Ilozor *et al*., 2004; Chong and Low, 2006; Forcada *et al*., 2012; Forcada *et al*., 2013; Pan and Randolph, 2015), but only a limited number have focused on their costs, which have been found to range between +3% to +5% of original construction costs should they come to light (STATT, 1989, Mills *et al*., 2009). However, it is recognised that the longer a defect remains unidentified, the greater the costs to rectify the problem, if or when it becomes apparent, particularly in the case of substructure and structural elements.

Rework can materialise at various stages in a project's life-cycle. Treating each phase as a subsystem of the project's system can enable boundaries to be established and costs to be apportioned. Though it needs to be acknowledged that errors can span over several boundaries if they are not able to be identified. From a systems perspective, each subsystem may appear to be explicit, comprised of rules expressed by contracts that give rise to plausible behaviours. But the underlying assumptions and work conditions that underpin the contracted work that is played out can generate behaviours within each of these sub-systems. Taking a systems' thinking perspective, provides the ability to look beyond a person's motivation or actions that has resulted in additional costs due to rework, and understand that behaviour as expressive of structure. To address the counterproductive behaviour may require changes to the system's structural design of the project system and the way in which rework is accounted. However, before the structural design can occur, there is a need to make sense of rework as there has been a tendency to oversimplify why rework occurs or dismiss its presence (Love *et al*., 2018c)

4.0 Measurement of Rework

Seldom, if ever, does rework form an integral component of a project's cost accounting in construction. Typically, rework is identified under the auspices of a contractor's non-conformances, and therefore construction changes and omissions are ignored and excluded. The measurement of rework therefore presents several challenges as it is not anticipated to occur in projects. Systems that are put in place are not established to capture or record its costs (Love *et al*., 2018a;b). With the absence of a standardised rework definition contractors are unable to undertake operational benchmarking, which is needed for them to engage in a process of continuous improvement.

While rework tends not to be formally measured by construction organisations, studies have attempted to capture its costs using a variety of approaches such as *work shadowing* (Josephson and Hammarlund, 1999), *cost of quality methodology* (Low and Yeo, 1998; Barber *et al*., 2000; Aoieong *et al*., 2002; Tang *et al*., 2004; Jaafari and Love, 2013), providing 'guesstimates' using questionnaire surveys (Love, 2002a; Hwang *et al*., 2009) and the development of specific classification systems (Burati *et al*., 1992; Rogge *et al*., 2001; Love and Irani, 2003; Robinson-Fayek *et al*., 2004). While tentative rework costs have been able to be determined, the actual figures experienced in construction remain a 'known, unknown' due to a paucity of standard measurement procedures and processes (Love *et al*., 2018a).

5.0 Rework Causation

Studies identifying the causes of rework in construction are ubiquitous (e.g. Robinson-Fayek *et al*., 2004; Canadian Owners Association of Alberta - COAA, 2006; Aljassmi and Han, 2013; Hwang *et al*., 2014; Taggart *et al*., 2014; Jingmond and Ågren, 2015). Many such studies have identified singular causal factors and have not acknowledged the interdependency and complex relationships that lead to the occurrence of rework in construction (e.g., Hwang *et al*., 2012; Aiyetan, 2013; Kakitahi *et al*. 2014; Ye *et al*., 2015; Yap *et al*., 2017). Repeated singular rework causal factors identified include poor communication, workmanship and quality management. However, these factors lack clarity; for example, what does poor communication mean? An example where a lack of understanding of the nature of communication comes to the fore in Ye *et al*. (2015) as they state that rework was caused by a "poor communication path of project instructions". Ye *et al*.'s (2015) observation oversimplifies the complexity associated with how people interpret information. In explaining this complexity, Busby (2001) suggested that problems do not arise because X does not communicate Z to Y, but rather because of the way that Y interprets Z in light of some prior experience (or lack of), which X does not know about. Thus, X fails to make allowances for Z, and Y does not realize that X does this, as Y thinks that both their experiences are similar and representative.

The focus on identifying singular causes has thwarted progress toward developing strategies to reduce and contain rework as the underlying conditions that trigger the events that result in its manifestation have been overlooked. Moreover, most studies examining rework causation have discounted the fact that it occurs due to an error being made by one of the parties, except when change-orders are involved. The role of human error has been acknowledged and addressed in Atkinson (1999; 2002), but since the publication of these works only few studies in construction such as Aljassmi and Han (2013) and Taggart *et al*. (2014) have recognised its primary role in rework events. In contrast, within the domain of civil and structural engineering the role of human error in safety and failure has received widespread attention (e.g., Blockley, 1985; Brown and Yin, 1988; Melchers, 1989; Eldukair and Ayyub, 1991; Han *et al*., 2013).

So, to recognise the causes of rework, there is a need to systemically understand 'why' and 'how' errors are made at the individual, team and organisation level. At the individual level errors can be classified as: (1) *action errors* (i.e. goal orientated behaviour that is consciously regulated or via routines), which are unintentional deviations from goals, rules and standards (Frese and Keith, 2015); such errors are composed of mistakes (a wrong intention is formed) and slips and lapses (failure of execution) (Reason, 1990); (2) *violations*, which are a conscious intention to break rules or not conform to a standard (Hofmann and Frese, 2011); and (3) *judgment and decision-making errors*, which arise due to cognitive biases and heuristics (Weber and Johnson, 2009). In construction projects, most people work in teams or groups. Thus, consideration should be given to how individual and team errors are made in group processes (Sasou and Reason, 1999), though for some reason research has eschewed this line of inquiry in construction.

While on face value individual errors may have been perceived to have contributed to rework, 'organisational errors' can also be at play. Organisational errors refer to actions of multiple participants that deviate from specified rules and procedures, which may result in adverse outcomes (Goodman *et al*., 2011). Again, research examining the nature of organisational errors in construction has been passed over with an overwhelming preference to superficially identify causal variables from a micro-oriented perspective (e.g., Hwang *et al*., 2012; Aiyetan, 2013; Kakitahi *et al*. 2014; Ye *et al*., 2015; Yap *et al*., 2017).

While individuals naturally commit errors, it is the project environment and their organisation that often provide the conditions for them to occur. A series of pathogenic influences arise from strategic decisions (e.g., market strategy and conditions) made by construction organisations and enacted through managerial actions in their projects (e.g., resourcing, schedule pressure, subcontractor selection, and procurement) provide the setting for errors to be made. For example, Love *et al*. (2018c) observed that descriptions for numerous non-conformances stated that items had been installed incorrectly across a wide-range of projects and sometimes repeatedly on the same one. It was found that supervisors had not been able to perform an inspection or check an item prior to its installation as they did not have the capacity to do so due to a lack of resourcing. This situation of vulnerability to error tends to emerge as a by-product of competition and operating in an environment where low profit margins predominate. Considering this example, previous research such as that presented in Ye *et al*. (2015) would suggest the cause of having to re-install items would be either "poor quality of construction procedure" or "poor admission of materials/equipment". Such attributions are nonsensical as they provide no meaning and context, which is needed to understand the environment that resulted in the rework to be performed.

Errors are systematically connected to aspects of people's tools, tasks and their environment. To ensure quality, people must negotiate with multiple system goals; for example, the economic pressures that a contractor needs to manage, the project's schedule, safety, the method and sequencing of construction and subcontractors. Thus, there is a need to understand the organisational context within which people work in projects if the causal nature of rework is to be determined and subsequently reduced. Despite the sheer number of studies that have sought to ascertain the causes of rework, there remains limited knowledge about the dynamics and the interactions that lead to errors being made in construction.

Indeed, causal modelling techniques such as systems dynamics models have been aptly applied to conceptualise, visualise and simulate the interactions and interdependencies that may exist between variables that contribute to rework (e.g., Cooper, 1993; Rahmandad and Hu, 2010; Han *et al*., 2012; Han *et al*., 2013; Parvan *et al*., 2015). Often, they have been underpinned by assumptions that purport to represent reality rather than being grounded in empirical data. An example where a logical and plausible assumption does not reflect reality can be found in Love *et al*. (2008) where it was considered that the error-proneness of designers was commensurate with experience. Here the assumption was that the more experienced a designer was the less likely they were to commit an error. According to Reason (1997), however, more experienced designers are more likely to take risks with the consequences of their actions being more profound than their inexperienced counterparts. Unless headway is made to understand how the work setting of construction organisations and their projects influences the occurrence of errors, then rework causation will remain a paradox that continues to be misunderstood.

Possessing an orientation toward subjectivity may provide the basis for making progress to better understanding rework causation and the nature of project system from where it has materialised. Team members within a project system each possesses mental models of reality that create and sustain its identity, and ability to learn and change. People's mental models eliminate feelings of ambiguity and influence how the project team think and act. But mental models are subjective and are therefore unable to be measured. There is a form of orientation whereby mental models are communicate people's tacit knowledge and experiences with rework causation and these are presented in a format that is 'understandable'. That is, they can be discussed within the context of the work setting (e.g., cognitive and causal mapping). In doing so, people need to be cognisant and refrain from imposing their own value judgments on the models of others that may be put forward for discussion (Bonnema and Broenink, 2016).

6.0 Influence of Project Characteristics on Rework

There appears to be a commonly held belief that time, cost and quality levels vary with different procurement methods, project types, by their size (i.e., contract value), and purpose. Yet research has repeatedly demonstrated that a project's characteristics (e.g., procurement method, project type and size) do not influence cost and schedule performance (e.g., Ireland, 1985; Naoum, 1994; Walker, 1995; Love *et al*. 2017). Hence, do project characteristics influence the incidence of rework and its costs in construction projects? If so, why would they as errors form the basis of rework and are systematically connected to tools, tasks and the work setting within which people work?

Relying on scant empirical evidence, CIDA (1995) indicated that projects procured using traditional lump procurement methods that did not implement a quality system experienced rework costs that exceeded 15% of their contract value. Hwang *et al*. (2009) reported that rework costs differed between: (1) heavy industrial and buildings; (2) projects of US$50 to US$100m and >US$100m; and domestic and international projects. Considering these differences Hwang *et al*. (2009) were unable to provide a rational explanation as to why they occurred. In a similar vein, Forcada *et al.* (2017) identified a significant difference between building and civil infrastructure projects. The explanation put forward was that building projects are more complex than civil infrastructure. However,, the study did not measure complexity and provide a context of the scope and nature of works that were constructed. Again, Forcada *et al*. (2017) suggests that there is a difference between rework costs in projects procured by private and public sector and those delivered by a joint venture or sole contractor. However, no practical rationale as to why this would be the case is provided. Moreover, Forcada *et al*. (2017) do not define a 'joint venture' and 'sole contractor' within the context of a procurement method.

In stark contrast to the above, Love (2002a) found there to be no significant difference between project characteristics and rework costs. This finding was again reiterated in Love and Sing (2013) and Love *et al*. (2018a). If arbitrary results such as those presented in Hwang *et al*. (2009) and Forcada *et al*. (2017) are unable to be justified, then they should be treated with considerable caution or even disregarded. Evidence explicitly indicates that organisational and managerial decisions and actions are the underlying mechanisms that provide an explanation for the occurrence of rework and its negative impact on project costs (Barber *et al*., 2000; Robinson-Fayek *et al*., 2004; Taggart *et al*., 2014).

The complexity of a project system and the incidence of rework is an area that has received limited attention within the literature. Projects will naturally vary in their complexity (e.g., organisational and technological) due to their degree of differentiation and interdependency but how their integration is managed is the key their successful delivery (Baccarini, 1996). Central to managing the integration process is the way in which problem solving is addressed. The decisions that are taken will impact other parts of a project. By anticipating the impact of potential trade-offs will inform the choices that will be made. So, when an error, for example is identified, blame should be avoided and instead attention should be placed on the problem that is be glossed over. Essentially, the following question should be asked "what is it about the problem that we do not understand?" Considering the above discussion, it is not so much the characteristics of the project that influence rework, but way they are managed and the willingness to see a situation more fully, to recognise interdependencies and to realise that multiple interventions can be used to address the problem. Context and reflexive practice are important for addressing rework with curiosity and courage being needed to engender change.

7.0 Impact of Rework Project and Organisational Performance

Clearly, rework can negatively impact project cost and time performance. As noted above, the costs of rework can be significant and increase project costs. Research undertaken by Love (2002a) demonstrated that rework contributes approximately 52% of a project's cost growth experienced in construction projects after design changes and omissions are excluded. In the case of schedule overruns, Love (2002a) and Forcada (2017) have revealed that rework in their sampled projects contributed to increases of 20.7% and 15%, respectively. Notably, rework does not always contribute to a schedule overrun being experienced as delays may be accommodated within a project's total float or slack. For example, Forcada (2017) found that a third of the projects sampled did not experience an increase in schedule. Thomas and Napolitan (1995) demonstrated that when changes are required, and rework needs to be performed, a daily loss in labour productivity in the range of 25% to 50% can occur. Furthermore, the key issue contributing to disruptions was the absence of materials needed to enable the rework to be undertaken (Thomas and Napolitan, 1995).

Having to execute rework can also adversely influence worker morale, increase their stress levels, and even result in absenteeism. In this instance, productivity is also negatively impacted. However, while rework is being carried out the likelihood of a safety incident occurring significantly increases (Love *et al*., 2018c). If an accident occurs while rework is being undertaken, work on-site can be temporarily halted and investigation may be undertaken. Such losses in productivity and costs have yet to be empirically quantified. However, the costs tend to be absorbed by a contractor and can be considerable, particularly if several accidents occur over the course of their project portfolio.

The profitability of construction organisations is probably impacted by rework, though the extent has remained unknown due to the unavailability of data being provided by contractors for reasons of commercial confidentiality. In a first, Love *et al*. (2018a;b) working with a several *Tier One* contractors have been able to determine the tentative impact of rework on their profitability. Based on the issue of non-conformances that were recorded and required rework, it was found that contractors experienced a staggering loss of profit of 28% and 34%. It is well known amongst the contractors that rework has adverse consequences on project and organisational performance, so why does it continue to plague their construction projects? This is a question that continues to stupefy many scholars and practitioners, especially as rework has been recognised as being a problem for a long time (Moore, 2012). No claim is made to provide a definitive answer, but several avenues of research do merit further study. One avenue that is worthy of exploration is to utilise the philosophy of systems thinking as it can enable an awareness about the role of structure that creates the conditions for rework to be examined. Moreover, by engaging system thinking a realization that actions have consequences, which may have been previously oblivious to construction organisations. Systems thinking provides a disciplined approach to asking questions and therefore can encourage managers and employees to develop a restless, inquiring mind.

While an array of strategies, techniques and tools are available to mitigate rework seldom are they integrated and appropriately implemented. Improving *constructability* is a robust strategy for reducing errors as it focuses on the ease and efficiency with which structures can be built and in part reflects the quality of the design documents. If the design documents are difficult to understand and interpret, the project will be difficult to build. Seldom, however, is construction knowledge wholly integrated and relied upon during the design process, even when non-traditional procurement methods are utilised. Furthermore, design audits and reviews of documentation can iron-out design issues and ensure redundant items are identified prior to construction. While this is the responsibility of designers, such practices tend to be undertaken on a piecemeal basis and whether they can be accommodated within the competitive fees that are charged is another matter. Practices that can be used to reduce and contain rework are disregarded as they have a cost associated with them. Designers rarely take responsibility for their errors, and once works commence on-site there is a perception that if they are identified they become the contractor's problem (Love *et al*., 2018a).

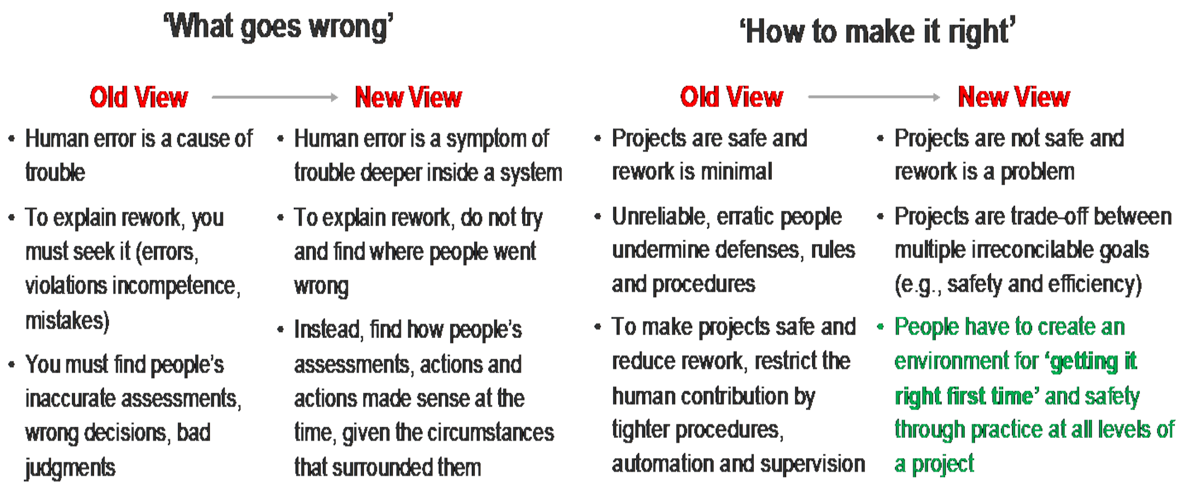
Some strategies, such as *lean*, have been applied to construction with the aim of eliminating non-value adding activities without understanding 'why' and 'how' they are caused, particularly rework. Applying ready-made solutions to a *wicked* problem that is not understood is akin to 'fitting a square peg in a round hole' or a 'solution looking for a problem'. Without any doubt non-value adding components in a process can be removed, but this does not stop people from making errors. An inability to comprehend the dynamics and nuances associated with error is asphyxiating construction organisations as there appears to be an overwhelming mindset that they are damaging to them. When errors do arise, employees may conceal them to avoid informing managers of bad news, by presenting information that does not adhere to their beliefs, or both. The practice of hiding mistakes is institutionalised in many organisations and therefore concealing problems becomes a standard practice (Ford and Sterman, 2003).

8.0 Rework Reduction and Containment

When rework comes to light contractors are confronted with ‘uncomfortable knowledge’ (Rayner, 2012). Strategies that have tended to be adopted to deal with its presence are to: (1) deny that there is a problem; (2) dismiss it is a minor issue; (3) divert attention away from its occurrence; and (4) displace its presence by suggesting that progress is being made to address the issue at hand. Acknowledgment that rework is a problem and a willingness to redress its occurrence are the first steps that organisations need to reduce and contain rework. The effects of rework are not only borne by construction organisations, but can also be felt by design firms. When examining rework from the perspective of design changes and omissions, then the core practices that will be suggested hereinafter are also applicable to the design organisation. No single panacea exists to abate rework, but empirical-based research and drawing on the extant literature creates a way forward to reduce and contain errors.

For organisations responsible for construction, there is a need to engage and enact *error management*, which also needs to be adopted by organisations funding or are affected by construction. Under the auspices of error management organisations should be encouraged to take a ‘new view’ of errors as they are a symptom of a poorly performing system (Figure 3). Unfortunately, errors have typically been viewed as being indicators of poor performance rather than of system behaviour, and when they do occur there is a natural reaction to apportion blame and engage in hindsight bias. Errors are deemed to be a cause of trouble for organisations and therefore are seen as an aberration from normal operations. This view of ‘what goes wrong’ has resulted in construction organisations adopting an ‘error prevention’ mindset of errors that can and needs to be prevented (Figure 3). This old view of ‘what goes wrong’ has resulted in construction organisations adopting an ‘error prevention’ mindset of errors which assumes errors can and needs to be prevented (Figure 3).

The new view focuses on 'error management', which commences once an error has occurred and seeks to alleviate its negative consequences or impact through design and training (Frese and Keith, 2015). It involves coping with errors to avoid their negative consequences. When an error is identified, it is attended to as quickly as possible to control any adverse impact that may arise. Knowledge relating to causes of errors are identified and shared to reduce their future occurrence. Error management also optimises the positive consequences of errors to engender long-term learning, performance and innovations.



Adapted from Dekker (2006: p.xi)

Figure 3. Shifting mindset: From the need to 'prevent' errors to acknowledging errors 'happen'

The common practices used to support the establishment of an error management culture are (Love *et al*., 2016): (1) communicating of error; (2) sharing error knowledge; (3) helping in error situations; (4) quick error detection and damage control; (5) analysing errors; and (6) coordinating error handling. Error management should not be a replacement of 'error prevention' but be seen as being supplementary to practice. Managers need to be mindful that differences in error-related processes affect individual and organisational outcomes. Error management processes should be categorised based on their time frame (i.e., before and after an event has occurred) and whether interpersonal processes are involved (i.e., open communication about errors versus hiding them). The detection of errors is therefore the most important aspect of error management and needs to be underpinned by a no-blame environment. Two stages of evaluation need to follow the process of detection: (1) *error* *identification*, which is concerned with knowing what was done wrong and what should have been done; (2) *error recovery*, which involves knowing how to undo the effect of the error and achieve the desired state. The complexity of the task being undertaken influences the extent of error detection that is undertaken. It holds therefore that the more complex a task, the less likely an error will be detected. For example, the design process of a construction project is deemed too complex. At the project level an example of where error detection comes to the fore is the process of conducting design audits and checks (Figure 4). Traditionally this process is labour-intensive and can be time-consuming, and therefore costs design organisations a portion of their fees, which impacts their profit. Perhaps the way forward is through the use of a BIM to reduce rework costs. In addition, constructability assessments can be performed and visualised in three-dimensions to understand the positioning and installation sequence of work to be done (Figure 5).

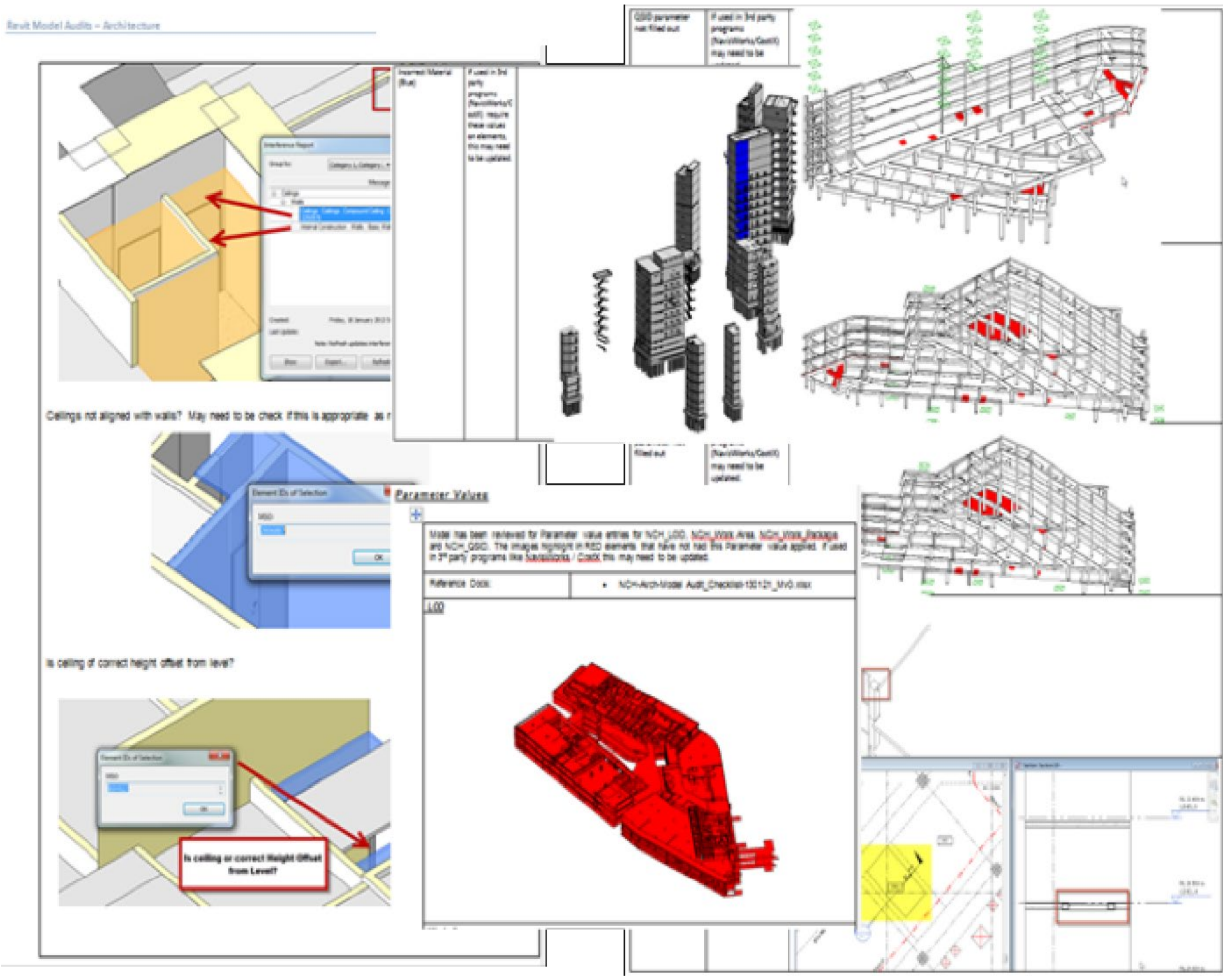


Figure 4. Design auditing and checks within a BIM

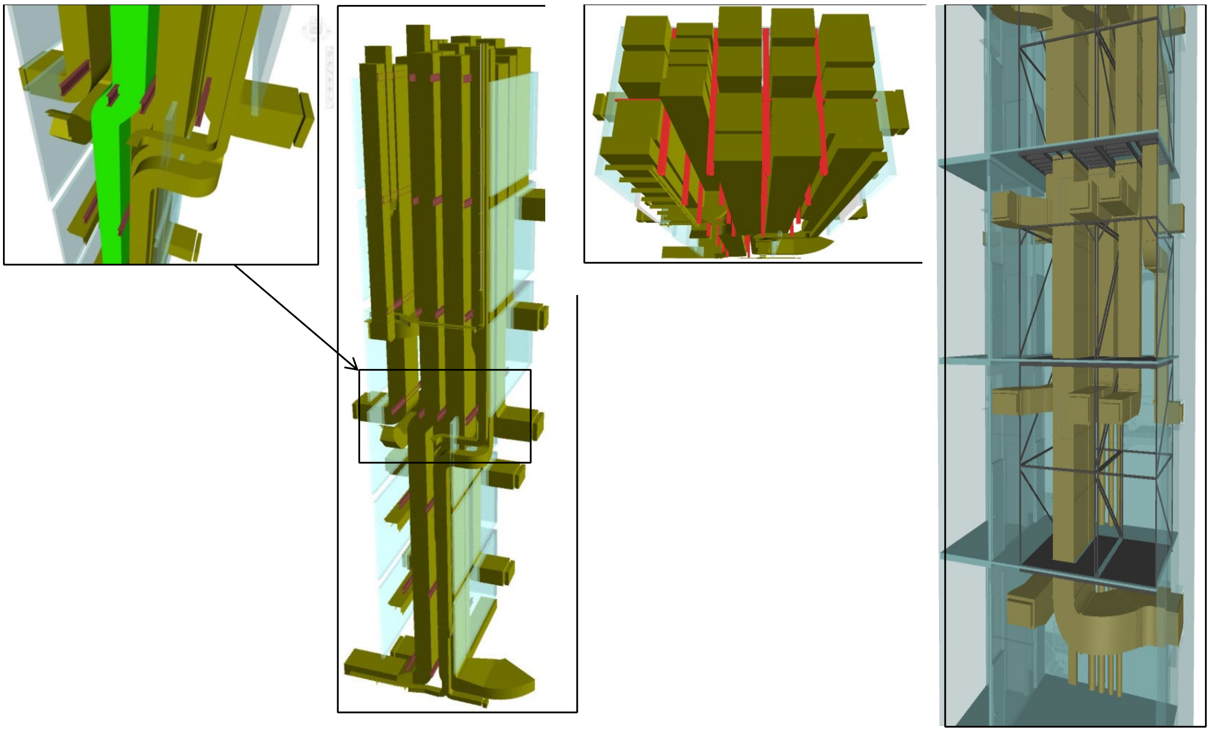


Figure 5. Visualisation of ductwork to aid constructability in a BIM

Error detection (e.g., coordination errors) can become a continuous process that is extended beyond design to the operations and maintenance phases of a project (Figure 6). The creation and capturing of information in a digital format can help the knowledge sharing process, communication collaboration and aid decision-making - all of which are essential to support error management. Prior to handover laser scanning can be used to verify the 'as-built' model and detect possible errors and that may arise during operations and maintenance (Figure 7).

In the case of an asset owner, for instance, if they can 'think about the end at the beginning'; that is, their data requirements to operate and manage a facility, then changes in scope may be, in theory, minimised. The use of building information modelling and associated digital technologies (e.g., laser scanning, augmented reality, and photogrammetry) have a role to play in detecting errors and enabling them to be communicated and shared between team members in real-time (Ding *et al*., 2017), but it needs to be made explicit that they are simply an enabler of error management. When an improved understanding of rework causation emerges, then the benefit of digital technologies will be able to be realised in practice.

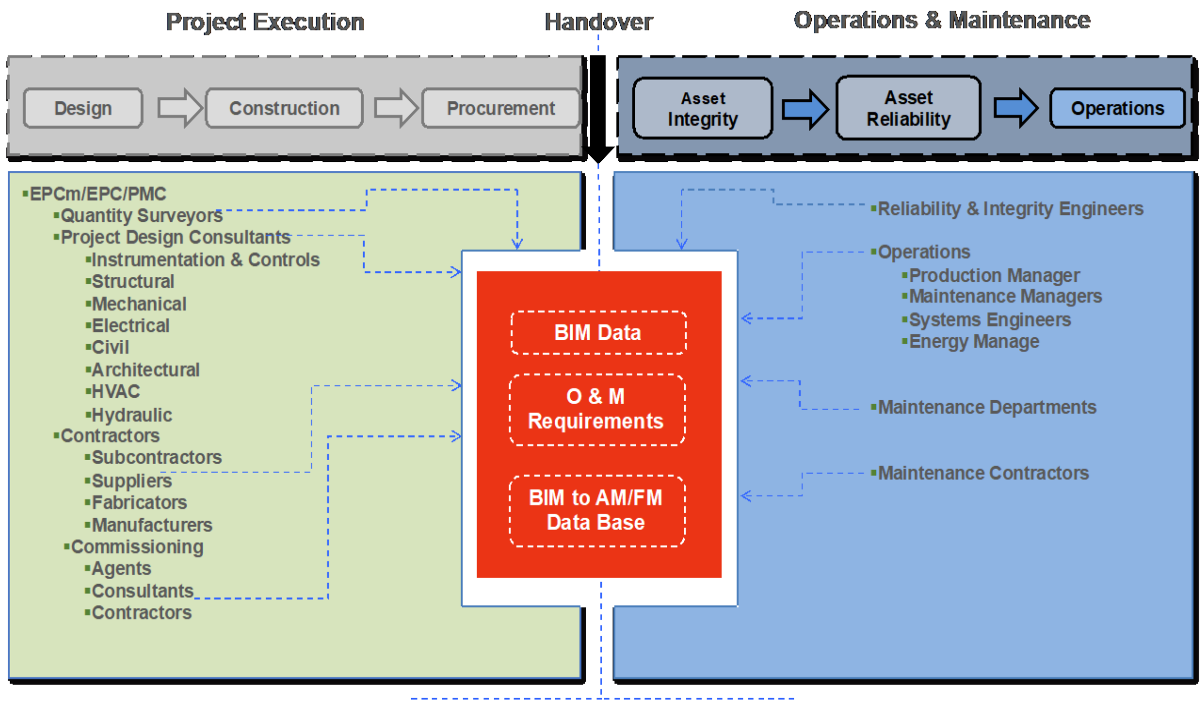


Figure 6. Asset information management: Minimising changes, errors and latent defects

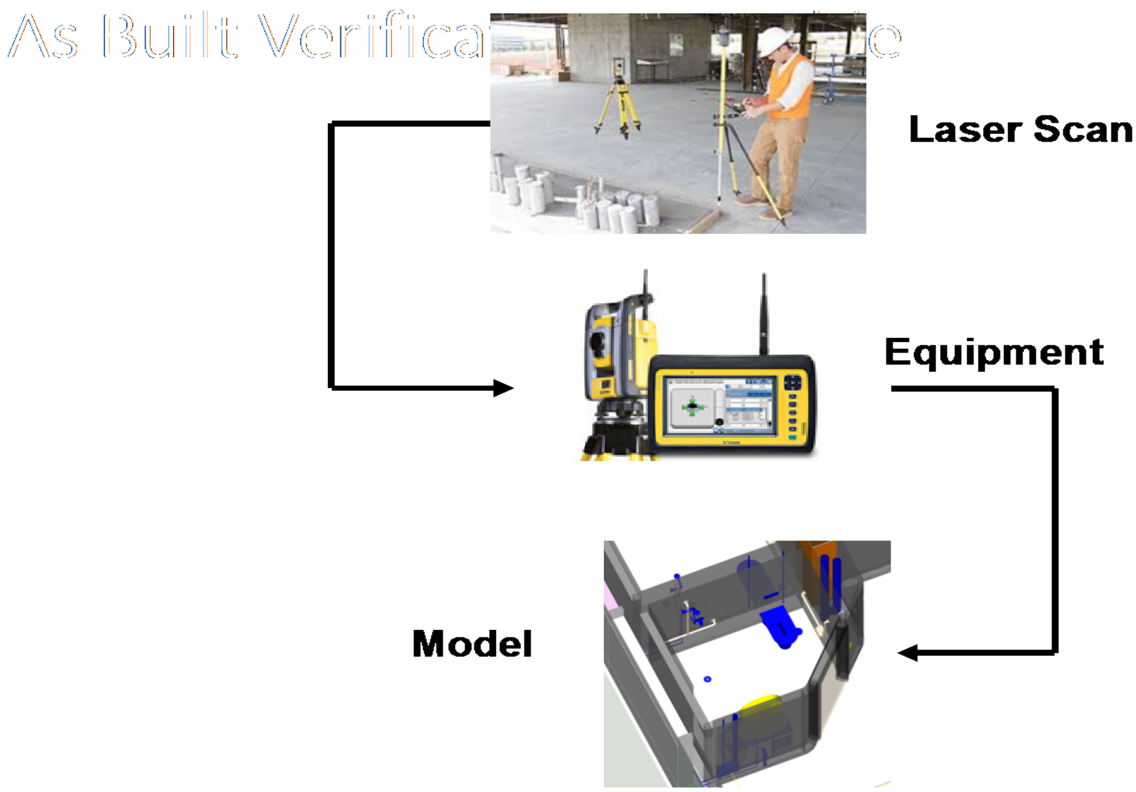


Figure 7. Scanning to verify 'as-built' BIM

The challenge, however, is the cultivation of an attention to detail that enables individuals and project teams to be able to improvise and handle errors as they are identified and to ensure they are not repeated. Organisations need to be prepared for errors and not rely on the use of procedures and systems (e.g., quality management) and expect them to shield and screen errors out. In preparing for errors, individuals and teams should seek out that which is non-routine to enable creative and meaningful solutions to be identified. Admitting to an error and developing an action plan can improve trust and confidence between project teams as it provides an acceptance of their responsibility. However, errors that occur because of a conscious intention to break a rule or that are non-conforming to a standard, can often result in blame being apportioned. In developing solutions to reduce and contain rework, it is pivotal to understand the type of error that is being committed and why it is occurring.

9.0 The Role of Clients, Practitioners' and Professional Bodies

With tighter profit margins and the need for higher productivity levels, clients and their project teams cannot ignore rework, as their competitiveness is being jeopardised. It is in the best interests for public and private sector clients, and organisations operating in the construction industry to ensure positive strides are being made to avert errors that result in rework. A unified effort is required to improve the performance of the construction industry. A call of this nature has been previously made several times by government and industry bodies worldwide (Egan, 1998), but it has fallen on deaf-ears as there has been an absence of a desire and motivation to embrace change from within organisations. It would appear, however, that the tide is beginning to turn as there has been a public acknowledgment that error is a problem in the construction industry. For example, with the support of the Institution of Civil Engineers, clients such as *Network Rail* and numerous leading contractors, the 'Getting it Right Initiative' has been established with an aim to significantly reduce errors in the United Kingdom construction industry. The initiative's specific objectives are to:

- change the attitudes of those involved in the sector so that they care about and focus on reducing the number of errors and improving the quality in what they do;
- improve the knowledge across the sector so that all involved properly understand the ways that design and construction processes can be disrupted and how this can and often does lead to error and waste; and

- improve the decision-making and planning skills across the sector so that all involved can react and adjust to unavoidable process disruption.

The Chartered Institute of Building's (CIOB) Construction Quality Commission launched its call for evidence into construction quality following a series of high-profile quality failings such as the discovery of structural defects in the Edinburgh Private Finance Initiative for schools. According to the CIOB a focus on price and programme has driven the wrong behaviours, leading to quality being neglected. This observation resonates with the findings presented in Love *et al*. (2018d) which revealed that construction organisations often placed unrealistic cost and schedule constraints on their project teams, which were then placed on subcontractors where people tended to deviate from established working procedures and routines to make their work more efficient and cost less. This not only resulted in rework but also safety incidents occurring. As a result of the 'Getting it Right Initiative', Tier 1 contractors in Australia have also banded together to kick-start a similar approach. The change needed to ensure that quality becomes a mainstay of practice, as is the case of safety, requires the backing of government and the formulation of regulations to uphold and enforce its importance in construction.

10.0 Implications for Practice and Research

Explicitly there is a need for construction organisations to develop a standardised nomenclature to classify and determine rework costs. There appears to be a groundswell of support for this to occur but the form that this nomenclature will take and how it will be useful for benchmarking will require construction organisations to work collaboratively to ensure quality becomes a core feature of every day practice.

To support the change that is required to ensure that rework is given the authority it deserves, there is a need for organisations in construction to recognise and admit that their prevailing culture and behaviours provide the environment for error-making. Such errors not only impact the quality of work that people perform, but also on their safety. It is generally not well-understood why people working in construction commit 'cognitive failures' (i.e., slips and lapses) and how they can be prevented in the workplace. Following a period of exposure to stress a predisposition exists towards cognitive failures and minor mental health symptoms. Thus, providing people with the knowledge and ability to cope with stress could reduce the need for rework. This is an issue that has received limited attention in construction.

Errors relating to knowledge can be addressed through training and education (e.g., developing a competency-based quality certification), but in the context of rework, training/education is an area that has been overlooked. By implementing error management, knowledge-based errors that arise can be identified and actions instigated to address this issue. Yet, learning of this nature is seldom practiced in construction organisations, as limited attention is paid to critical reflection during and on completion of a project. In fact, the urgency to complete the project and move on to the next one mitigates against the type of reflection of weaknesses needed. Determining the type of errors that typically result in rework would also help organisations understand how their work environment is influencing peoples' cognition and behaviour.

The transition from an error prevention to an error management culture is not a straight forward process and requires an organisation to develop a change management strategy where there is buy-in or commitment from people throughout all its levels. Prior to initiating any form of change initiative, it is necessary to establish a base-line of existing views and practices to error management. Initially assessing an organisation's 'error orientation' using the instrument developed by Rybowiak *et al*. (1999) allows one to assess the behaviour and attitudes individuals display when confronted with errors. Then, using the 'error management culture questionnaire' assess the error culture of the organisation, rather than to an individual's error orientation (van Dyck *et al*., 2005). Leadership, however, is needed here to instil the notion that there will be no blame apportioned to error-making, though those acts are purposeful and depending on their severity need to be addressed using a different strategy. Determining the conditions that result in and the way to address procedural violations is a line of inquiry that is yet to be explored in construction.

11.0 Conclusion

Rework remains a problem in construction, despite the considerable amount of research that been undertaken, as there is an absence of generic concepts and a common language to identify and describe its systemic characteristics. The lack of development has contributed to a series of factoids about the costs and causes to rework being reported in the literature that are not representative of practice. This paper has aimed to shed light on rework by providing unpacking the ambiguity that surrounds rework and has suggested that to make sense as to 'why' and 'how' it occurs as well as its costs, there is a need to develop a questioning mindset, which has been absent from practice in construction. To engender this mindset, it needs to be acknowledged that rework materialises as a result of series of interdependent actions that cannot be considered in isolation. To understand the nature of rework causation therefore requires the adoption of systems thinking as it bolsters the ability to understand the structural dynamics of a project's systems and thus enable managers and decision-makers identify an avoid unintended consequences. With advances in technology projects will become complex as their organisational structures and processes will be required to accommodate and facilitate the communication of information and knowledge. This can increase the capability to examine situations from multiple points view enabling the determine of most effective leverage actions and opportunities to mitigate errors.

Initiating and engaging in productive conversations within projects and more widely with industry stakeholders about rework and its adverse consequences can enable high quality interactions and engender a process of continuous learning. Discussions offer a forum to present ideas and offer strategies to reduce and contain errors that manifest as rework. However, changes to the practice of construction are required to shift it from a standpoint where errors can be 'prevented' to a position that they are acknowledged to 'happen'. This swing can occur by with taking a systemic view where patterns of behaviour observed and the underlying structures that drive rework are identified and understood.

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