Get It Right Initiative

Improving value by eliminating error

Literature Review

Revision 3 – April 2016

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Current practice review

> *"The cost of quality is one type of measurement that can provide the user with information about rework and activities designed for its prevention. It is a measurement that could be considered after-the-fact, because it occurs after the action has occurred. Thus, the measurement of rework should be used as a mechanism to learn from the past to improve on the future."*

(Love et al. 1999)

1. Introduction

The Get it Right Initiative has been established to help the construction industry to understand the causes, and reduce the impacts, of error and rework.

This section of the report looks at academic and industry research into error and rework in construction, and explores some of the proposals which have been made to reduce the cost of rework and improving quality. It is important to note at the outset that the definition of rework includes both necessary rework – arising from client changes – and unnecessary rework, brought about by errors in the development process.

This cost of rework has become such an endemic feature in the construction process that contracting organisations now build expectations of time and cost overruns into their procurement processes (Love & Li 2000)

In the UK, the Egan Report – Rethinking Construction (Egan 1998) – suggested that up to 30% of construction is rework. The report went on to make suggestions as to how to reduce this figure, setting a target of 20% reduction in defects (on handover) per year, assuming that zero defect construction could be achieved in five years. The Egan recommendations covered procurement and efficiency enhancements, and adopting process improvements to increase consistency and efficiency.

Such an improvement would have a dramatic impact on the costs of construction and contribute significantly towards the Construction 2025 targets of a 33% reduction in the initial cost of construction. However, while progress has been made in reducing error and rework since Egan, industry surveys suggest that progress remains slow.

For example looking at the latest Glenigan construction industry KPI reports for Constructing Excellence, we can see that there is a marked improvement on defects at handover since 2001. There remains more to do, with only 71% of clients rating their satisfaction with regard to defects at handover as eight out of ten or better.

The impact of rework and error is not a phenomenon restricted to the UK; work on the impacts and causes of rework has been undertaken in many countries, with key papers emanating from Australia, Singapore, South Africa, the USA, Canada and the UK.

There are many academic papers on the impact of construction rework, in particular, from Australia where one of the most prolific academics in the fields, P.E.D Love, is based. However, Love's findings have been repeated in other countries and, given the similarity between the UK and Australian economic systems the findings are considered to be translatable to a UK context.

2 Estimates of the financial and economic impact of error in the construction industry.

The financial and economic impact of error and rework in construction varies widely by project, with reported impacts ranging from 0-80% of project costs. A commonly reported average of 5% (approximately £5bn in the UK) is supported by several papers. However, in the context of a specific project this average is almost meaningless.

Discussion

The Egan report quotes a (1998) figure of 30% for the cost of rework in the USA, Scandinavia and the UK. Love & Edwards (2004) showed that earlier work on rework costs reported values of between 3 and 15 per cent of a project's contract value; Barber et al. (2000) suggest rework might be as high as 23% of contract value; Simpeh et al. (2015) found that the total rework costs range from 0% to 75%.

The degree of variability is akin to another study undertaken by Love (2002), where some respondents reported rework costs to be less than 1% of a project's original contract value, while others reported them to be as high as 80%'

However, as rework continues to be a significant issue for the industry, commentators tend to put the cost of rework at around 5%. For example, a geniebelt.com blog post cites the 5% figure. This would equate the cost of rework in the UK industry to £5.1bn.

Several recent studies have provided support for use of 5% as an average approximation of rework in construction. For example, Hwang et al (2009) undertook a new study of 177 construction projects and found that the average owner reported rework cost was 5.0% across all projects. Further, research by the USA's Construction Industry Institute (CII) reveals that direct costs caused by rework average 5% of total construction costs (CII 2005) (but range from 0-25%).

While across projects the average cost may be in the region of 5%, the reported disparity indicates that the degree and cost of rework is highly context sensitive. This suggests that predicting the amount of rework on a given project is likely to be challenging. This will be explored further in section [3.1.4.2] below.

The 5% rework figure is generally accepted as the 'right sort of figure'. However, the studies are far from in agreement on the cost. Differences in the definition of rework and data collection methods used, indicates that rework costs could be significantly higher than figures reported in the normative literature (Love & Smith 2003).

For example, Love (2002) shows that while the direct cost of error and rework in terms of cost and materials can be high, the indirect impacts can be up to five times that of the direct costs. Not all studies include both direct and indirect costs of rework.

Love & Edwards (2004) confirm the existence of indirect impacts, but find them to be lower than reported in Love's (2002) sample. They found that rework contributed 52% of cost overruns in projects.

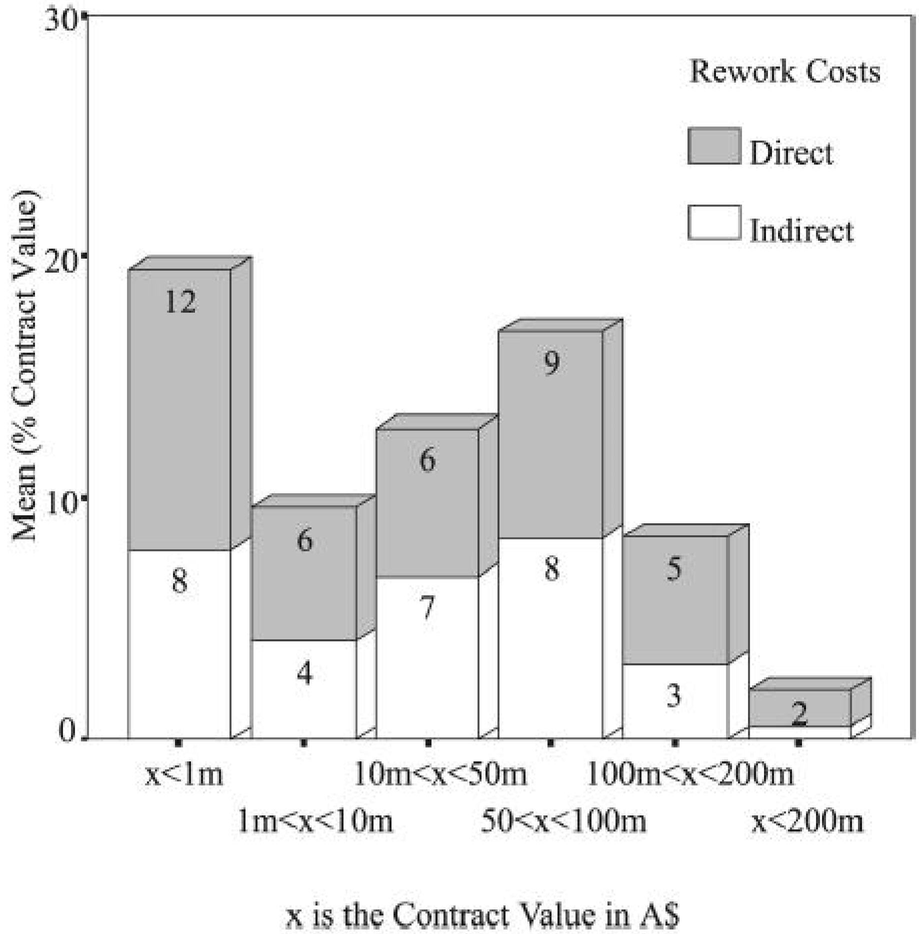

Figure 1 – Mean rework costs for project by contract value - Love & Edwards (2004)

Much depends on the projects under review. There are so many variables contributing to the level of rework that sampling a small number of projects is quite likely to lead to the identification of outlying data.

So while the 5% average figure provides an industry wide average to apply at a national level, it is unlikely to provide a good indication of the likely rework on a particular project.

3 The principal causes of error in the construction industry

Understanding the cause of errors

The answer to the question as to the principal causes of error and rework in the construction industry is not straightforward.

Reason (1995) describes errors as arising in one of three ways:

- failures of intention where the plan is inadequate (failure to plan). Reason (1995) terms these failures of intention 'mistakes' and distinguishes between :
  - rule based mistakes which involve the misapplication of a rule, the application of the wrong rule, or not applying the right rule for a given context; and
  - knowledge based mistakes which occur in novel situations and require significant cognitive processing, which is prone to bias.

- failures in execution (slips and lapses), where a plan is adequate but the actions do not go as planned. These can be further sub-categorised as failures of
  - recognition;
  - attention;
  - memory; or
  - selection.

  Slips and lapses usually occur in familiar surroundings while someone is performing a routine task.

- deliberate violations which can arise from:
  - routine violations, or cutting corners;
  - optimising violations, to address a personal objective (such as going home early) rather than task objectives; and
  - situational violations which 'offer the only path available to getting the job done, or when the procedures are seen to be inappropriate for the present situation'.

Each of these causes has different psychological origins and requires different counter measures (see Michie et al. 2011 for a discussion on diagnosing and encouraging behaviour change).

These classifications provide a comprehensive basis to analyse the reason an *identified* error was made. However, in a complex supply chain the root cause of an error may not be immediately apparent.

Accordingly, researchers have also analysed error and rework caused by the nature of the deviation: carelessness, ignorance, or recklessness; by their consequences or causes (Reason 1995); by type of deviation; by construction phase origin; or by cause type – error, omission or change. There is little agreement in the literature as to which is the most appropriate approach to recording errors.

Indeed, Reason (1995) suggests that there is no one taxonomy which can serve all needs in describing errors, and as such, the search for a unifying taxonomy may ultimately be fruitless.

In recognition of the possibility of error or violation, companies develop quality checks which are intended to trap errors before they manifest as rework or accidents. Where rework occurs, there will have been both a failure in process and a failure in the quality checks designed to eliminate such errors.

As a result, when we look for the causes for an error, we need to understand not only the root cause - that is where and why a problem arose – but also why the problem by-passed opportunities for that problem to be captured, before becoming manifest as an error requiring rework. A third related area for exploration is the systemic conditions which prevailed to allow the problem to arise in the first place.

The remainder of this section describes the root causes of error as described in the literature and considers systemic conditions which contribute towards the errors. The next section will explore the tools for classifying and recording errors.

The identified causes of error

In 1981, in response to increasing media attention on the quality of product from the construction industry, the BRE undertook a study of 27 sites to ascertain the sources of 'Quality related events' (Bentley 1981). Of the 501 events they identified, approximately 25% were described under the heading of 'unclear or missing project information'; a further 17% arose from 'lack of care'. They reported that of errors in building projects they found 50% had their origin in the design stage and 40% in the construction stage.

In particular they found that:

> *'In general, quality standards on site did not rely significantly on formal checking and acceptance or rejection of completed work. Instead, they resulted from the clerk of works, together with the site agent, putting great efforts into creating an environment where good work could and was likely to take place'.*

It should be noted that this work is pre-Egan, and much has been done in the industry to improve site practices. However, design related causes of rework continue to dominate.

Burati et al. (1992) produced a taxonomy of error sources combining different actors of the process: client; designers; constructors; transporters and fabricators, with the reason for the rework – errors, omission or change – along with sub-categories of design change. Their study found that design changes, errors, and omissions account for 78% of the total rework costs experienced in the reviewed projects. Willis & Willis (1996) report that design omissions and errors alone account for 38% of the cost of rework.

Hwang et al.'s (2009) work simplified Burati et al.'s (1992) taxonomy, reducing the number of categories from 19 to 9. Their review of rework on 177 projects found that in each class of building, either 'designer error or omission' or 'client changes' were the primary source of rework. Across the study, these two categories accounted for 30% and 26% of all rework respectively. Similar findings were reported from the contractor reported statistics.

It is relatively straightforward to understand how client changes, in particular late changes, can create rework. Such changes are deemed to be necessary changes to enhance value delivered to the client, but can cause disruption in the programme and lead to further error or rework.

Love & Edwards (2004) discuss the impact of client initiated changes, suggesting the use of early design freezes as a technique for reducing the impact of client changes. However, they also rightly highlight that this approach might conflict with meeting client requirements. An alternative approach might be to have staged freezes or gateway approval points towards which the entire supply chain works.

The impacts of design errors and omissions

The quantity of rework arising from designer errors and omissions is worthy of further note. According to Love et al. (2008), the quality of design documents is often considered inadequate for its intended purpose. They support this statement with a statistic that 'design-induced rework has been reported to contribute more than 70% of the total amount of rework experienced in construction and engineering projects'.

The term 'designer' here is not limited to the architects and engineers who lay out the initial plans and design intent for the building, but also the subcontractors who often undertake detailed design for fabrication and construction.

Along with a sobering catalogue of design-based construction failures, Lopez et al. (2010) discuss the causes of design error and omission. They also show that erroneous design documentation is a significant contributor to rework and that 'information contained within design documentation [can be] contradictory and subsequently requires changes to be made.'

This is particularly critical when delivery schedules are compressed and lower tier subcontractors need to start work on fabrication early to meet delivery deadlines.

The drivers of design errors are described by Lopez et al. (2010) under the headings (*inter alia*)

- Adverse behaviour
- Inadequate training of design consultants
- Competitive fees
- Ineffective utilisation of Computer-Aided automation
- Inadequate quality assurance (both on-site and off-site)
- Unreasonable Client and End User expectations
- Ineffective Coordination and integration of the Design team
- [Lack of] Design error prevention

These drivers begin to give suggestions as to how errors and rework might be reduced. Figure [2] below shows Love et al.'s (2012) findings from their systems model of design errors which support these findings.

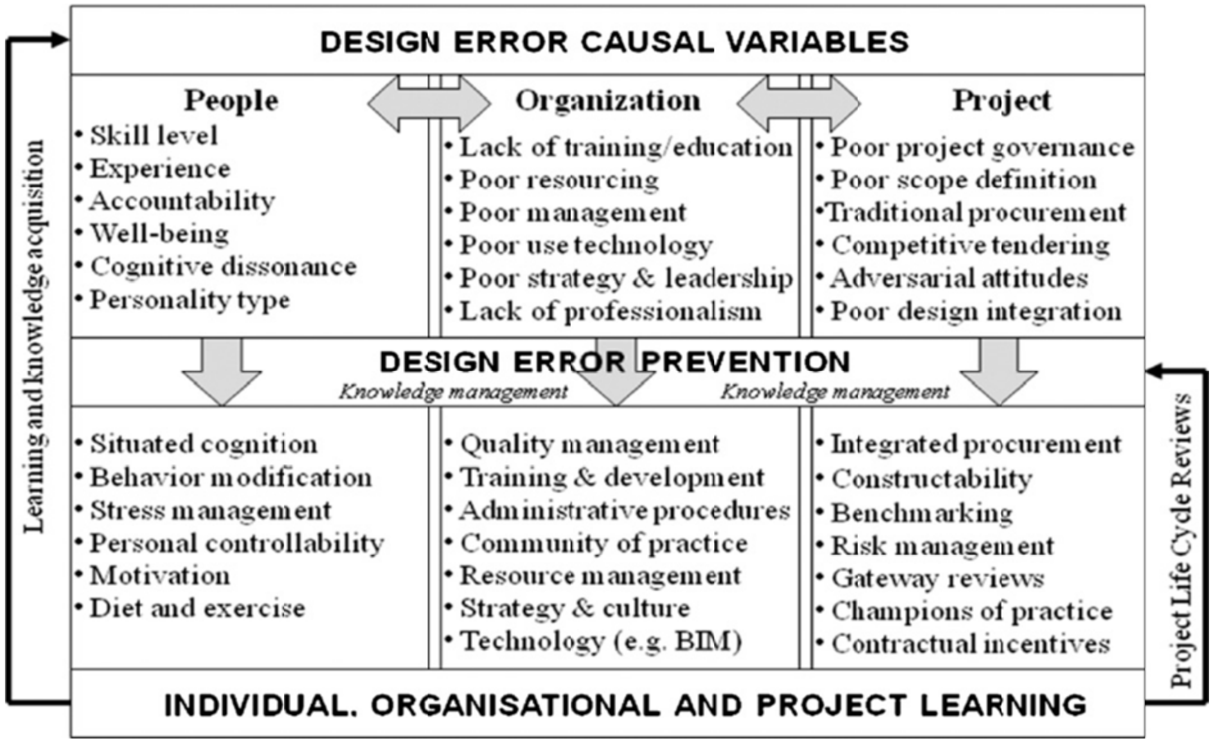

Figure 2 from Love et al. (2012) – causes and prevention of design errors and omissions

Systemic issues

Love et al. (2011) have described the sources of error as pathogens which exist at a project, organisation or an individual level. We can see from figure [2] that there are several such pathogens which can potentially create errors. However, many of these pathogens are initiated by issues outside of the control of the design team, and are discussed briefly below.

Industry fragmentation

Researchers often cite the fragmentation of the construction industry as a block to good practices. Gann (2000) describes how this fragmentation arose and the impact it has had on risk allocation.

EC Harris (2013) produced a supply chain analysis of the construction industry for the UK Government which explores the impacts of fragmentation on the industry, highlighting in particular:

- a lack of time & resource available to both the designers and the [tier 2/3/4] suppliers and sub-contractors means that designs may be incomplete or incompatible and may lead to error;
- that fragmentation of the industry increases the amount of overhead and margin included as ‘on-costs’;
- The importance of good site management – both soft and hard skills – in bringing the disparate organisations together on site. This reinforces the point made by the BRE in their 1981 report on quality in construction on creating a quality site environment;

The EC Harris report made several recommendations which will support the Construction 2025 objects. For the purposes of this report, the key recommendations include:

- 'Investment in the development of the quality and capability of site management staff in order to drive performance improvement through supply chain interaction on site;
- Better alignment of construction industry improvement agendas with the interests and priorities of the supply chain, including procurement and risk transfer practice;
- Encouragement through procurement practice of effective early sub-contractor engagement;
- Investment in capability development throughout the supply chain to increase the adoption of performance improvement initiatives.

Similarly, Simpeh et al. (2015) discuss the separation between the design and construction [and fabrication] processes and describe how this separation 'inhibit[s] communication, coordination and integration among project team members', setting a context for error and rework.

Overcoming these issues by aligning participants around a common delivery process on which they can work collaboratively was the aim of Rethinking Construction. This collaborative approach can deliver significant benefits, but the approach has yet to be widely accepted (Wolstenholme 2009). EC Harris (2013) 'found that over half of those surveyed considered the benefits of partnering were 'patchy' and that people paid 'lip service to the Egan agenda''.

Time and costs pressures

This poor communication and coordination is exacerbated by client desire to complete projects quickly to keep costs down. To deliver a building in an acceptable timescale, tenders are necessarily let based on incomplete information. The detailed design is not complete and design intent may not be finally settled.

This incomplete information is then passed on by the tier one contractors to their supply chain for costing and further detailed design. Concurrently, the design continues to develop.

Subcontractors and suppliers are likely to be under pressure to begin detailed design on incomplete drawings where there is greater time pressure. This will be exacerbated by poor communication across the supply chain.

4 The tools and methods used to classify and record error, the causes of error and the financial and economic impact of error in the construction industry

Due to the complex nature of the construction industry, and the variety of definitions and interpretations of error or rework, there has been little agreement as to a common classification system for recording errors and rework. This leads to uncertainty over the true scale and source of the issue.

There are many quality tools available to help to trace and classify error, for example '3 Legs, 5 Why', Root Cause Analysis, 8D, Failure Mode & Effects Analysis (FMEA) but it is not clear from the literature to what extent these are used in the construction industry.

Discussion

To enable consistency of reporting, researchers have sought, and continue to seek, a common taxonomy to describe causes of error and rework. Unfortunately because of the complex and interconnected nature of the industry, there has been little agreement between authors as to which taxonomy use.

This section explores the various views which researchers have developed of the problem.

Burati et al.'s (1992) taxonomy of 19 sources of loss provided a coding structure within which to analyse the source of errors and rework. Their analysis was an *ex post* review of CII members' reported project deviations on 9 projects, using a series of decision rules to provide consistency to the process. The analysis, however, was constrained by the use of descriptors developed by the CII's quality management task force. This limited the opportunity for developing significant novel insight.

An alternative approach which has been adopted is the use of Root Cause Analysis (RCA). This approach helps to identify the key factor which caused a particular outcome. RCA seeks to identify potential causal factors by exploring the sequence of events and conditions which led to the problem occurring. This can be achieved using tools such as '5 why' (ask "why?" five times), cause and effect (Fishbone or Ishikawa diagrams) or a drill down technique.

The literature presents 2 examples of the use of fishbone diagrams in rework identification, and these are reproduced below. The headings represent the top level of the descriptive buckets the researchers found. The populated hierarchies provide a rich source of data to analyse.

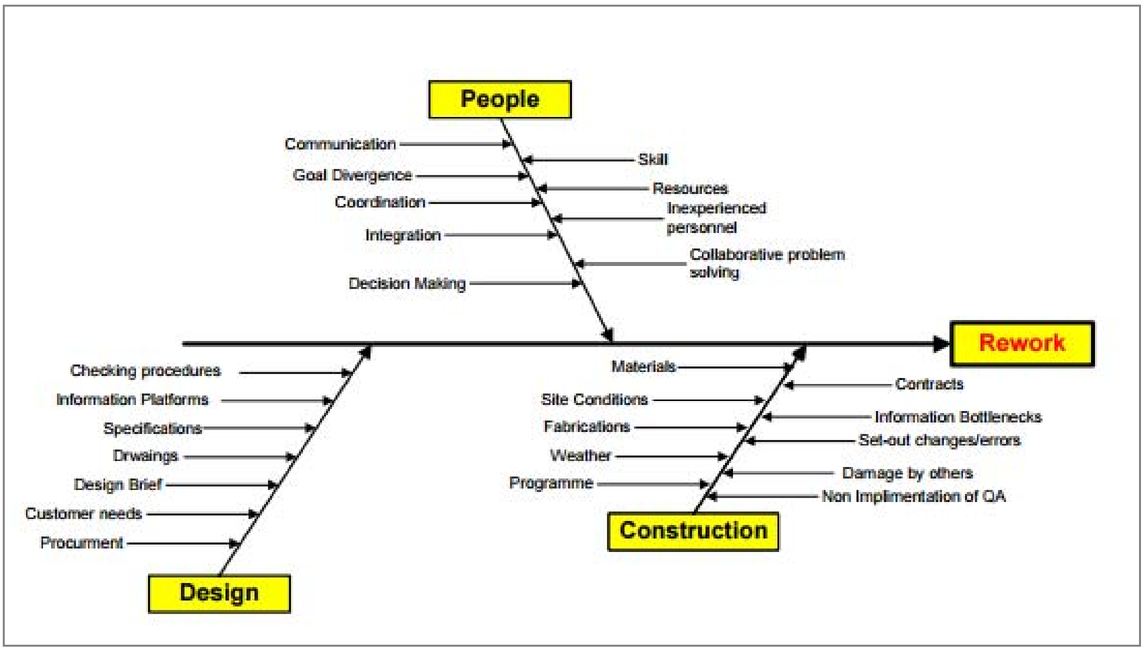

Figure 3 from Love et al. 1997 – Generic cause and effect rework diagram

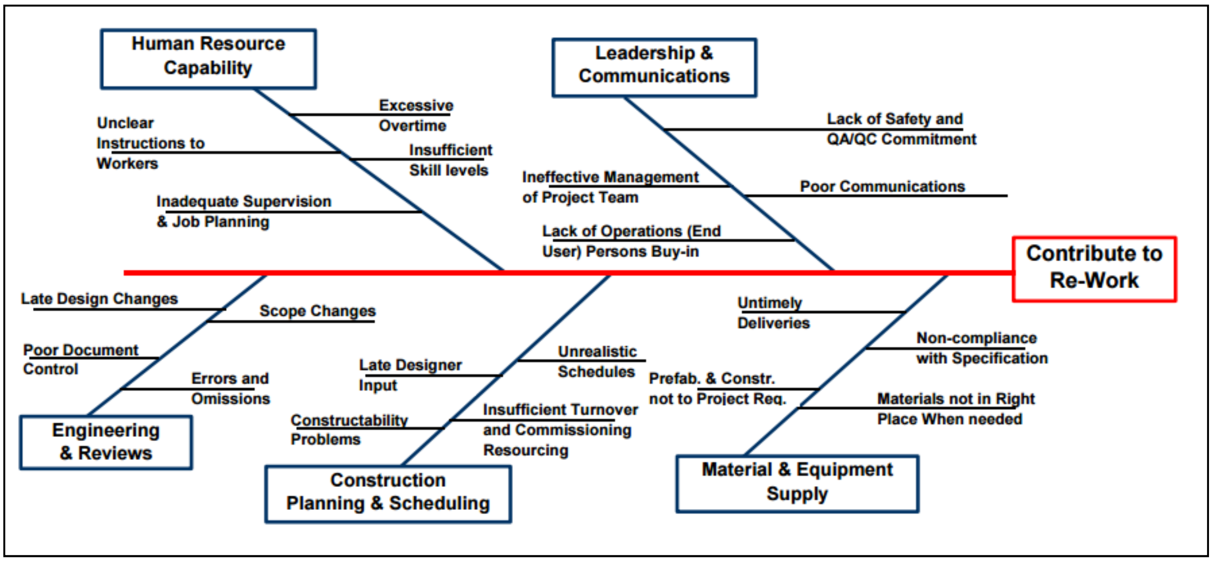

Figure 4 from Fayek et al. (2003) – COAA's Fishbone rework cause classification

Once the possible causes have been explored, the RCA enables the root cause – that which ultimately caused the problem – to be identified.

Recognising the complexity and interrelatedness of the issues involved in attributing cause to rework, Love et al. (2012) moved from a linear RCA model to a complex adaptive systems approach (Holland 1992) to help identify the drivers of design error and omission. This allows for key systemic, project and organisational issues to be uncovered [figure [5] below].

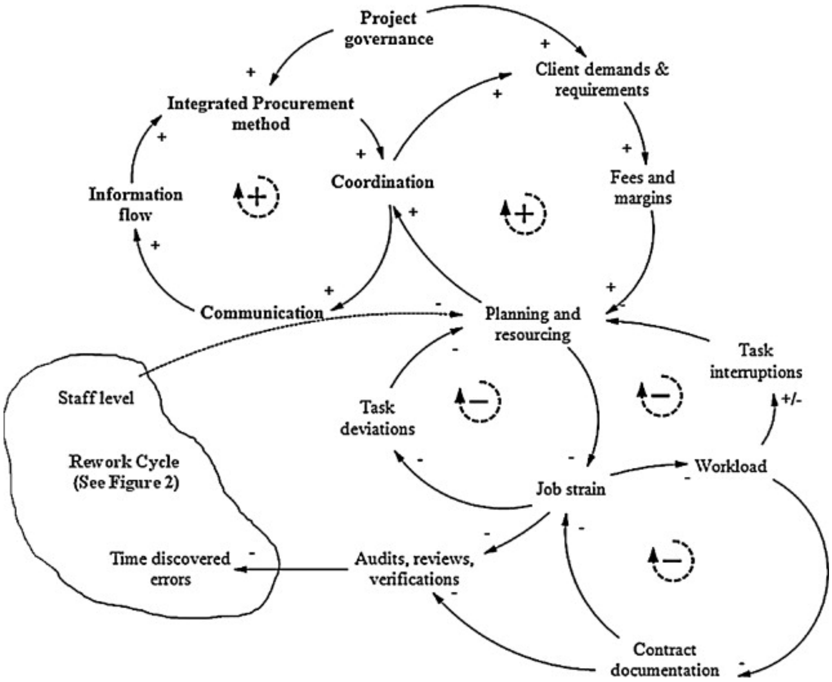

Figure 5 from Love et al. (2012) : Systems representation of causal influences on design error & omission

As highlighted earlier, there are many lenses through which to study error and rework, and until there is a form of standardised reporting, companies will develop quality reporting systems which best suit their organisational and data requirements relating to rework.

Fayek et al. (2003) confirmed that while many organisations maintain rework tracking systems, there is significant variation in the systems. Some are relatively simple, tracking just direct rework hours and reporting them as a percentage of the total. Other organisations recognise the importance of classifying rework to help identify what is causing them to undertake the most significant amounts of rework. The majority, however, ignore indirect costs of rework.

Lundkvist et al. (2014) also describe how tracking of defects and rework in industry often lacked consistency as project defect descriptions were often ambiguous and the records lacked important contextual information.

Fayek et al. (2003) propose a rework classification system, based on their fishbone diagram in figure [4] above, with a third level of classification providing a greater degree of granularity and descriptive power. Their approach uses the Analytical Hierarchical Process to allocate costs where multiple causes of rework are found. Their data capture enables detailed analysis of the rework data, including by work type (figures [6,7], table [1] below).

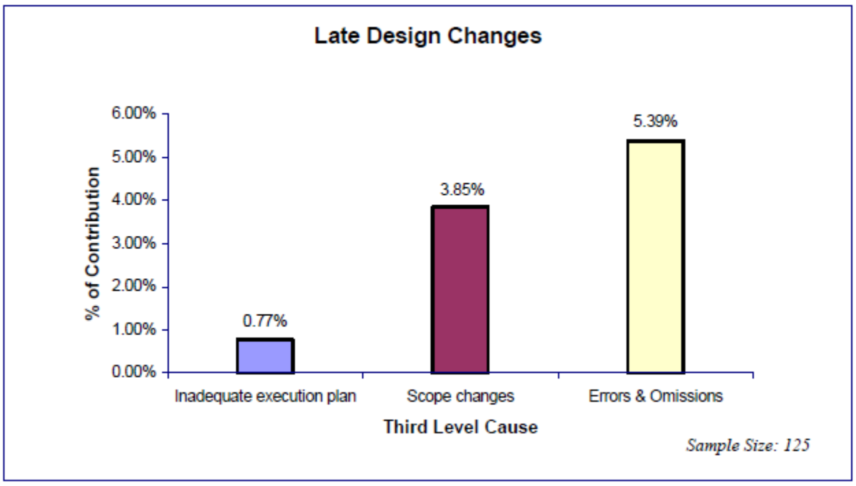

Figure 6 from Fayek et al. (2003) – illustrative date from third level data capture

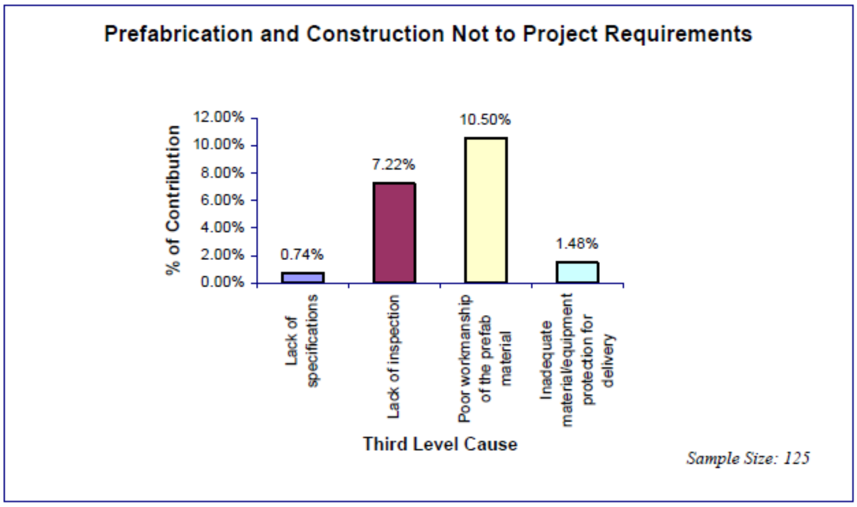

Figure 7 from Fayek et al. (2003) – illustrative date from third level data capture

Masterformat Activity Code	Description	Rework Cost Contribution ($)	% of Total Rework Cost
3300	Cast-in-place concrete	$ 89,588.19	15%
15105	Pipe fittings	$ 67,159.77	12%
15120	Piping specialties - supports	$ 50,369.83	9%
5120	Steel prefabricated elements	$ 41,974.86	7%
3210	Reinforcement steel for concrete	$ 26,876.46	5%
2310	Grading - Construction, shaping & finishing earthworks	$ 17,917.64	3%
2315	Excavation & Filling	$ 17,917.64	3%
3100	Formwork - Cast-in-place concrete	$ 17,917.64	3%
16060	Basic Electrical Materials - Grounding & Bonding	$ 17,917.64	3%
2775	Cast-in-place sidewalks	$ 17,917.64	3%
5090	Metal fastenings - Anchor bolts	$ 16,789.94	3%
5210	Steel joist members - structural steel	$ 16,789.94	3%
3130	Steel frames - permanent forms	$ 12,592.46	2%
7480	Exterior wall assemblies	$ 12,592.46	2%
2465	Drilled Caisson - Cut off elevation	$ 8,958.82	2%
2620	Pipe underdrain system	$ 8,958.82	2%
3360	Concrete Finishes	$ 8,958.82	2%
15150	Floor drains	$ 8,958.82	2%
13420	Instruments - Control valves	$ 8,394.97	1%
15140	Portable water piping	$ 8,394.97	1%
15760	Terminal heating & colling units	$ 8,394.97	1%
16120	Conductors & Cables	$ 5,016.16	1%
3400	Precast concrete structure	$ 4,197.49	1%
3600	Grouting - anchoring devices	$ 4,197.49	1%
5450	Metal supports - Electrical supports	$ 4,197.49	1%
5530	Metal fabrications - Gratings	$ 4,197.49	1%
6220	Finish carpentry (millwork) - standard pattern wood trim	$ 4,197.49	1%
6415	Countertops - installation	$ 4,197.49	1%
7100	Protective covers	$ 4,197.49	1%
7840	Firestopping - Includes material installed in cavities and around penetration	$ 4,197.49	1%
9910	Paints - Exterior & interior paintings	$ 4,197.49	1%
9970	Coatings for steel	$ 4,197.49	1%
10250	Service walls - wall assemblies and wall mounted units	$ 4,197.49	1%
11335	Sedimentation Tank Equipment	$ 4,197.49	1%
11500	Industrial and process equipment - Pumps	$ 4,197.49	1%
13020	Prefabricated building modules	$ 4,197.49	1%
13120	Prefabricated structures	$ 4,197.49	1%
13800	Door frames - installation	$ 4,197.49	1%
15070	Concrete inertia bases - for mechanical equipment	$ 4,197.49	1%
15110	Pressure regulating valves	$ 4,197.49	1%
15160	Interior rainwater drainage	$ 4,197.49	1%
15740	Water treatment equipment	$ 4,197.49	1%
15810	Ductworks - material & fabrications	$ 4,197.49	1%
15950	Equipment testing, adjusting, and balancing	$ 4,197.49	1%
	Totals:	$ 582,703.13	100%

Table 1 from Fayek et al. (2003) – illustrative date from data capture on locus of rework costs

5 The tools, approaches and methods which may be in use to reduce error in the construction industry

To improve the construction process, more attention should be paid to project planning and design … 'it's not rocket science'. BIM is expected to help encourage an early focus on coordination and planning.

The successful implementation of quality enhancement programmes is heavily dependent on communication and teamwork within and between organisations in the construction supply chain.

Quality enhancement techniques, developed in the manufacturing industries, provide examples of how process manufacturing organisations – such as house builders – might go about reducing their rates of rework. However, the bespoke nature of much of the non-residential building stock means that the approaches to improving quality within individual organisations has limited applicability to a fragmented supply chain.

Reducing errors in construction

Love & Li (2000) report that there are very few organisations (in Australia) which measure their cost of quality. As a result it is often difficult for them to prove that improving quality in their processes is worthwhile – the costs are real, the benefits are more challenging to identify, especially when they are avoided costs. It is not surprising therefore that companies neglect quality enhancing approaches which are deemed to increase cost bases.

However, Love & Li (2000) describe how such a quality investment can deliver longer term pay-off in the form of reduced rework (figure [8] below).

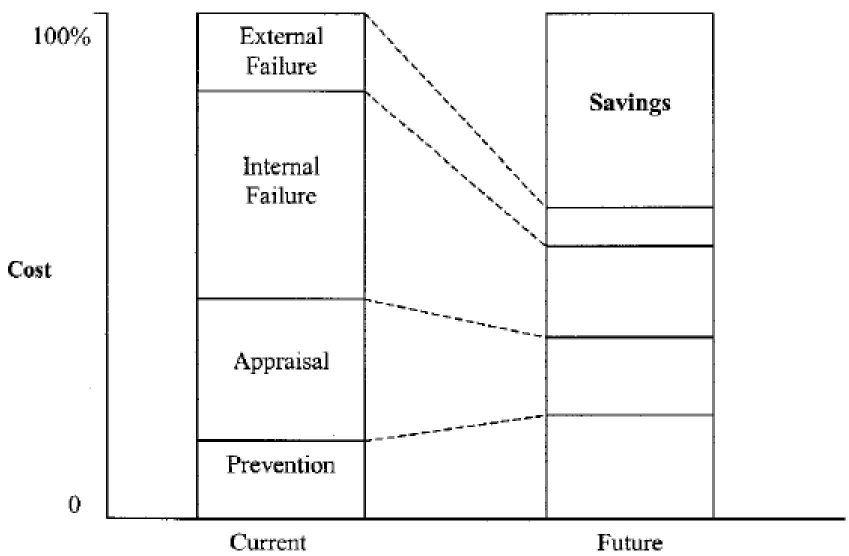

Figure 8 from Love & Li (2000) – indicative savings arising from investing in quality

Rework reduction tools

There are several tools which have been developed to assist reducing rework in construction

(COAA) Project rework reduction tool - PRRT

Building on the work of (Fayek et al. 2003), the PRRT is a software delivery of the COAA rework fishbone diagram from the previous section along with some guidance on best practice. It contains three elements: the Project Rework Reduction Index which provides an evaluation and rating on key field rework causing factor for a project; Suggestions and best practices / benchmarking based on best practice gleaned from industry; and a project dashboard to allow users to monitor progress.

The tool is comprehensive in its coverage, and has been downloaded at least 1,200 times. There is no indication of its use in industry however.

FRI

Recognising the cost of rework, the USA's CII undertook research into the drivers of rework (Rogge et al. 2001). Based on a review of 145 industrial construction projects they found a strong relationship between the amount of rework and alignment within the client organisation and the degree of commitment to constructability of the design and construction teams.

They concluded that to improve the construction process, more attention should be paid to project planning and design. As they readily admit, 'it's not rocket science'.

The CII took this as the starting point to develop a model which might provide an early warning as to amounts of rework on a given project – the Field Rework Index (FRI).

Love and Edwards (2004) provide a justification for such an index:

> *"Contractors are the custodians of the production process, hence they must receive 'the right' information to enable them to manage their subcontractors. Incomplete, conflicting, inappropriate, or changed information causes rework, which can delay the project's progress. Contractors' quality systems are unable to prevent errors and omissions which originate from consultants, nor can they thwart changes, but they can provide prevention mechanisms and give early warnings of poor quality."*

The FRI consists of 14 questions which project participants should complete before construction begins, rating each answer on a scale of one to five. These scores are then totalled and compared to an 'FRI Rework Danger Chart' (Figure [9] below). It will be noted that many of the questions focus on the likelihood of client changes or the drivers of errors or omissions in data from the design team.

									Points
1	Degree of alignment between the various elements (departments, divisions, etc.) of the owner's organization.	Could not be better	1	2	3	4	5	Could not be worse	
2	Degree to which project execution planning was utilized.	Completely	1	2	3	4	5	Not at all	
3	Design FIRM's qualifications for the specific project	Could not be better	1	2	3	4	5	Could not be worse	
4	Degree to which leaders of key design disciplines have changed	No change at all	1	2	3	4	5	Continual change	
5	Quality of field verification of existing conditions by engineering	Could not be better	1	2	3	4	5	Could not be worse	
6	Quality of interdisciplinary design coordination	Could not be better	1	2	3	4	5	Could not be worse	
7	Quality of prequalification of vendors for the project	Could not be better	1	2	3	4	5	Could not be worse	
8	Availability of vendor information for equipment	Could not be more available	1	2	3	4	5	Could not be less available	
9	Degree to which design schedule is compressed	Not compressed at all	1	2	3	4	5	Could not be more compressed	
10	Level of overtime worked by the engineering firm	None	1	2	3	4	5	Very high level	
11	Level of design rework (repeating design work)	Could not be lower	1	2	3	4	5	Could not be higher	
12	Commitment to constructability of the design and construction team	Total Commitment	1	2	3	4	5	Total lack of commitment	
13	Expected availability of skilled craftworkers to the project	Readily available	1	2	3	4	5	Very scarce	
14	Expected level of construction contractor overtime	None	1	2	3	4	5	Very high	

TOTAL POINTS

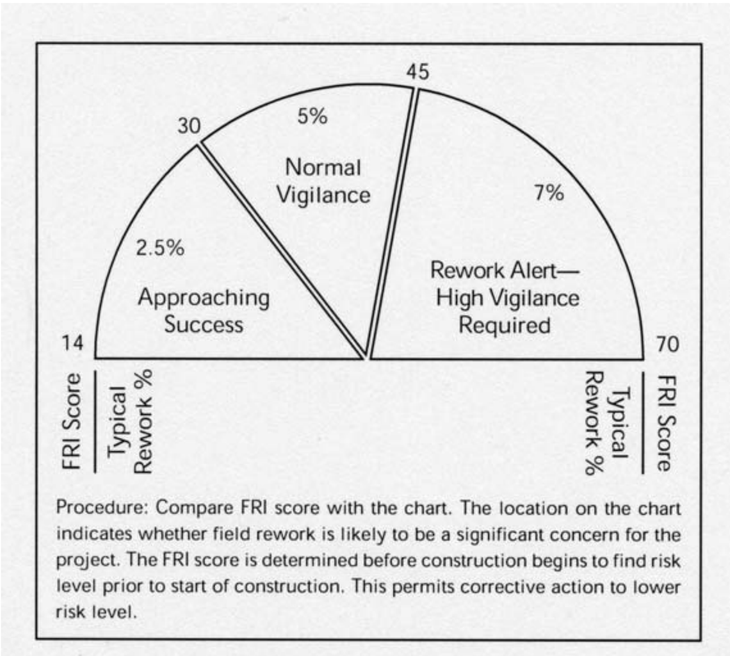

Figure 9 from Rogge et al. (2001) – FRI tool showing probability of rework.

In testing the process, the CII found a positive correlation between the rework anticipated by the model and the actual outcome. While the correlation isn't strong enough to accurately predict the amounts of rework, the model has been shown to provide a good indication as to the risk of rework.

This approach balances utility and simplicity well. The more comprehensive COAA implementation of PRRT is more complex and may have suffered as a result.

Some academics have gone further and attempted to predict the *probability* of occurrence of rework in construction. Love (2002) creates a probability distribution of rework based on 276 reported projects and show how anticipation and pre-planning can provide opportunities for the impact of rework to be reduced.

To date, little evidence has been uncovered as to their widespread use within industry.

BIM

Supporters of Building Information Modelling (BIM) highlight the opportunities for reducing error and rework in construction through using BIM approaches (Zghari 2013). This support is based on the understanding that if a building is modelled first in a virtual environment, the process of construction will be better planned and potential issues can be resolved before they get to site.

Such an approach does encourage and enable design teams to develop projects more quickly and to identify potential issues earlier in the process of development. However, there is no explicit requirement to engage with the lower tier subcontractors who will be delivering the project on site. Arge (1995) suggests that direct and constant communication between the architect and client/end-user is a critical factor that can affect the final product's quality.

Pre-planning allows for the better quality information to be issued, and is likely to aid in reducing error through the omission of information. However, in the absence of dialogue between consultant designers (architect, structural engineer, and M&E) and the delivery subcontractors (Love et al. 2011) slips, lapses, mistakes and violations are probable.

CII – Do it Right First Time

In 2005 the CII released findings of their 'Do it right first time' review in their report entitled 'Making Zero Rework a Reality' (rr203). The project had similar aims to this current project.

The CII highlighted the comparisons between the lack of improvement over the management of quality, and the improvements which had been made in the area of Health & Safety in construction.

They found that:

- rework reduction requires management commitment;

- staffing levels for safety were 67% higher than for quality;
- time spent on education and training on safety was six times higher than for quality;
- subcontractors were more commonly required to submit safety plans than quality plans; and
- trades were incentivised in safety related matters in 14 (out of 22) projects, quality incentives appeared in three.

This led to their proposing that quality be addressed and staffed in a similar way to safety with training being coordinated on known factors contributing to rework.

Quality management tools, and their limitations

> *"Clients demand improved service quality, faster building and innovations in technology. It is no accident that the construction industry has turned to the manufacturing sector as a point of reference and source of innovation. Successful concepts derived from manufacturing, such as Total Quality Management (TQM), Lean [..] Production and Reengineering, are being adopted and integrated into the construction industry. Implicitly, the successful implementation of these concepts is heavily dependent on a culture of teamwork and cooperation at both intra- and inter-organisational levels."*
>
> *Hoonakker et al (2010)*

In addition to the tools and approaches developed specifically to help overcome error and rework in construction, there are many quality management approaches which might be applied to the construction industry.

The approaches to product and process quality improvements available are listed by Quality-one.com under the headings of Development, Improvement and Corrective Action; broadly 'Plan – (Do) – Check – Adjust'.

In general, the approaches focus on adding client value and reducing waste. Their listing of approaches is included as an appendix along with a brief list of key papers in the field related to the construction industry.

On reviewing the more well-known of these models (eg Six Sigma, Kaizen, Lean) the methodologies appear well suited to the process driven manufacturing operations in which they were developed. The lessons can be applied to individual companies to assist in increasing the quality of their product. Indeed implementation and operation of the ISO 9000 series of standards aims to achieve a base platform on which these methodologies can be built.

However, the direct lessons of these quality management methodologies seem less well suited to long-term, bespoke projects delivered by a fragmented supply chain. In bespoke design, systems consolidators – architects and tier one contractors – will bring together a number of systems which may not have previously been built together and manage the interfaces. In such construction projects the site operations are generally less routine and are more contextually driven than for a mass manufacturing operation.

An exception to this in construction may be the process house builders, prefab buildings, or ‘out of the box’ schools and leisure centres. These are building models which can be improved across a series of implementations. In such process based environments builders are able to better manage and integrate the supply chain and new situations rarely appear. The same systems can be re-used together, reducing the uncertainty and likelihood of error and the need for rework.

Further, at the end of a bespoke construction project, the teams generally disband and move to the next project. The opportunities to learn from errors on a project are rarely captured and disseminated at an organisation level. Indeed, the learning points may be so specific to the context of a particular project that there may be little to be gained from such knowledge management.

6 Summary

The previous sections have highlighted the impacts and causes of error and rework in the construction industry and introduced methods which can be or are used to identify, monitor and manage rework.

The quality programmes identified are generally based on the model of Plan – Do – Check – Act. These seek to reduce the likelihood of errors arising in the first instance and catching them early should they do so.

The literature points towards the importance of a quality environment, led by the client and implemented by the tier one contractor. Further, the importance of allowing sufficient time for design development and reflection on decisions is highlighted.

The development of a quality environment may require a shift in industry thinking about quality. To aid this shift, we turn to Philip Crosby, “The Fun Uncle of the Quality Revolution“. Crosby is of the view that

> *“[t]o create a manufacturing process that has zero defects management must set the tone and atmosphere for employees to follow. If management does not create a system by which zero defects are clearly the objective then employees are not to blame when things go astray and defects occur” (Skymark.com)*

To support this position, Crosby’s outlines four ‘Absolutes of Quality Management’ which focus attention on how to improve quality across a process or project.

1. Quality is defined as conformance to requirements, not as 'goodness' or 'elegance'.
2. The system for causing quality is prevention, not appraisal.
3. The performance standard must be Zero Defects, not "that's close enough".
4. The measurement of quality is the Price of Non-conformance, not indices.

Appendix

A.1. Desk research – industry projects

This appendix provides some more background to quality management methodologies used across industries and introduces some of the UK industry initiatives to help reduce error and rework in construction industry.

A.1.1 – Methodological approaches to quality management

Plan – Do – Check – Act (or adjust)

At its most fundamental, the quality enhancement process can be described as an iterative four stage process, sometimes known as the Deming cycle. The four stages: Plan; Do; Check; Adjust (or Act) – PDCA – are necessary for continuous improvement in many of the following methodologies.

Each methodology represents an implementation of the PDCA approach, but will focus on either the whole or part of the process. Further, the levels of sophistication of implementation may vary, some approaches use statistical approaches to understand deviations, others may require more subjective views.

Total quality management - TQM

Total quality management consists of organisation-wide efforts to create a climate in which the quality of products and services to customers continuously improves through refinements in response to feedback. While there is no widely agreed-upon approach, TQM efforts typically draw heavily on the previously developed tools and techniques of quality control. TQM was superseded by ISO 9000, Lean manufacturing, and Six Sigma.

ISO 9000

The ISO 9000 family of standards addresses the issue of quality management systems. ISO 9000 deals with the basic concepts, principles and language of quality systems: ISO 9001 sets out the requirements that organisations need to fulfil in order to implement an accredited quality management system.

Certification to ISO 9001 is usually undertaken with an individual organisation, due to the need to have robust, controllable systems. It is the first step on a process of continuous quality improvement which requires organisations to have documented procedures in place which are followed to ensure:

- the control of documents, records and non-conforming products;
- the taking of preventative and corrective action; and
- the effective running of internal audits.

Other related standards are ISO 9004, which describes how to make quality systems more efficient and effective, and ISO 9011 which sets out audit guidance for quality management systems.

There are several industry specific implementations of ISO 9000 quality management systems to deal with the issues arising in those industries:

- Software development & IT: TickIT guidelines produced by the UK Board of Trade.

- Aerospace: AS9000, an interpretation developed by major aerospace manufacturers. The current version is AS9100C.
- Automotive sector: ISO/TS 16949:2009 is an interpretation of ISO 9001 agreed upon by major European and American automotive manufacturers which contains the full text of ISO 9001:2008 as well as some automotive industry-specific requirements.
- Telecom: TL 9000 is the Telecom Quality Management and Measurement System Standard, an interpretation developed by the telecom consortium, QuEST Forum. Unlike ISO 9001 or other sector-specific standards, TL 9000 requires the reporting of certain product and process measurements. This allows companies to benchmark their performance in key process areas. TL 9000 contains the full text of ISO 9001:2008.
- Medical devices: ISO 13485 governs the quality management systems of medical devices. It includes particular requirements for medical devices and excludes some of the inappropriate requirements of ISO 9001.

Lean manufacturing

Much of the emphasis of the available recent guidance in construction is focused on Lean production processes. Lean is a term that relates to a proven way of doing business, entirely focused on understanding and maximising customer value.

Lean classifies every activity into one of three types:

- Value Add - activities that a customer would be willing to pay for which help create the final form or function of the finished article
- Non Value-Add, but essential - things that need to be done, but that don't bring any value to the finished article (e.g. waiting for a document to print, the time it takes for paint to dry etc.)
- Waste - actions that bring no value to the article and are therefore unnecessary

To deliver lean processes, organisations pursue relentlessly the elimination of all forms of process waste and ensure that value-adding activities are completed in the most efficient and time-effective manner.

There are 5 stages to lean implementation:

1. Define what is meant by value to the final customer.
2. Map the physical, transformational and problem solving tasks which deliver value to the client. Use this map to identify waste and eliminate the waste.
3. Re-engineer these processes and tasks to deliver value in the most efficient manner.
4. Deliver.
5. Refine .

We can see how this can apply to a one organisation process. However, as the number of participants increases and the complexity of the value chain grows, the challenge of mapping and re-engineering the value delivery process becomes more challenging.

Lean has been implemented in their supply chains by the Highways Agency and BAA amongst others.

Six Sigma

Six Sigma was developed by Motorola in 1986 and is a highly disciplined, structured programme aimed at delivering near perfect products and services by improving processes.

It is an implementation of many aspects of TQM and acts as a business improvement methodology that focuses an organization on:

- Understanding and managing customer requirements
- Aligning key business processes to achieve those requirements
- Utilizing rigorous data analysis to minimize variation in those processes
- Driving rapid and sustainable improvement to business processes.

The six sigma process is generally directed towards improving the defect rate of a process to the level of defects per million opportunities. It is generally implemented top-down in an organisation, but stresses the responsibilities of those involved.

Kaizen / Kaikaku

Kaizen is Japanese for ‘continuous improvement’. The approach was developed in manufacturing industries and uses statistical control methods to spot and eliminate waste in business processes. The focus is on identifying and implementing a series of small improvements which can lead to large overall productivity gains.

The approach is used to empower employees to improve their product delivery. The process is based on standard procedures with are measured and then improved upon. This is a clear implementation of the Deming cycle.

Kaikaku on the other hand means ‘radical change’ and is most often implemented top-down to deliver significant change in a business, perhaps when kaizen stops yielding gains at the same rate.

Failure Modes and Effect Analysis - FMEA

FMEA is an approach to identifying potential failures in a design or assembly. The analysis aims to understand how a product in development might fail (to deliver the client brief) and to determine what the impact of those failures would be (using a root cause analysis or similar).

This process sits more within the planning phase of PDCA than across the whole quality management process. However, it can also be used as part of the checking phase.

Failures are then ranked according to the severity of the effects of failure; the expected frequency of failure; and the ease with which they can be detected.

8D design

8D is a problem solving methodology developed by the Ford motor company. The aim is to identify, correct and eliminate recurring problems arising in products and processes.

The process is relatively easy to learn and involves 8 stages (9 in some versions)

- Team formation
- Problem definition using diagnostic tools such as problem statements such as the ‘5 why’ approach;
- Interim containment action – stop the immediate problem – and confirm that you’ve done so.

- Root Cause Analysis to identify where the problem arose and to understand why the problem hadn't been previously identified.
- Permanent corrective action – identify & select actions to correct the problem and define success parameters.
- Implement and validate the corrective action.
- Prevention – update procedures, review similar processes retraining.
- Closure and team celebration – archiving, lessons learned and celebrate success.

The European Foundation for Quality Management's EFQM Excellence Model

The EFQM model is an excellence model designed to improve organisation quality in all areas, to surpass stakeholder expectations.

The model is an implementation of the PDCA approach to quality management, but is applied to nine separate areas of the business. These areas are made up of five enabler-based and four results-based criteria. The PDCA approach is applied to each of these criteria to drive aligned quality improvements in each area.

A.1.2 UK Industry specific initiatives to reduce rework

BRE

Construction Lean Improvement Programme

The BRE have been exploring lean production since the launch in 2003 of the Construction Lean Improvement Programme (CLIP). This was re-launched in 2009 to support the UK construction industry in its drive, inspired by the Egan report 'Rethinking Construction', to improve its financial performance, provide a better product and service to its customers, and cope with a skills shortage.

CLIP operates across the whole construction supply chain, from raw materials processors to clients providing the knowledge and practical skills needed to make change happen and to bring about real business benefit.

CLIP has created a number of programmes, tailored to the needs of construction but based on a successful Common Approach used across UK industry, that enable companies to make real and measurable improvements to Quality, Cost and Delivery performance, and to improve partnerships with customers and suppliers. There are lots of case studies and an introductory flyer from 2004.

On the back of this they launched a BTEC diploma in lean construction in 2006 and a construction lean awareness workshop (CLAW) which runs approximately quarterly.

BeAware 2005-08 research project

BeAware was managed by BRE in partnership with an industry consortium, led by a steering group of 15 partners and chaired by the Construction Products Association. The consortium consists of representative bodies from a number of sectors including the packaging, timber and woodworking, polymer and precast concrete manufacturing industries, among others.

BeAware examined 20 construction products to identify resource efficiency improvements. A simplified environmental assessment was carried out using life cycle assessment (LCA) data. The supply chain for each product was also investigated for resource efficiency improvements that could be implemented. Use of resources and waste generation associated with the product across its supply chain are the two key areas of focus.

The product assessment results and workshop outcomes have been used to produce a series of BeAware sector guidance reports that can be downloaded from the publications page.

CALIBRE & SMARTWaste

CALIBRE is a site efficiency and productivity measurement tool that diagnoses and quantifies 'waste' in man hours of non-added-value time. It identifies who is carrying out work on site and what they are doing, and where, when and for how long. Activity sampling determines the efficiency of the process and identifies delays and other non-added value activities.

The CALIBRE tool is used by BRE experts to help management teams to pinpoint where time and material waste is occurring in the construction process, using hard data obtained from measuring *site performance* [emphasis added].

The review is intended to lead to shorter delivery times, lower construction costs and reduced environmental impacts." It is coupled with SMARTAudit, a material waste audit tool and SMARTWaste, an online waste reporting platform .

A 2 page flyer with a bit more detail on the CALIBRE process is available.

CIOB

The CIOB published an article "The growing case for lean construction" in 2011. This links Integrated Project Delivery (IPD) with the use of Lean and BIM, suggesting that together they present a rational response to Egan/Latham.

CIRIA

In 2013, CIRIA launched a series of documents on Lean Construction to help industry participants to engage with the concepts in an efficient manner.

The documents were launched because even though many construction organisations and their clients are successfully practicing or exploring Lean as a way of delivering this value, there is still a lack of awareness and even some misunderstanding.

CIRIA produced 6 guides which explore different aspects of Lean.

Lean construction and BIM (C725)

This guide contains a clear description on the links between Lean and BIM, and how these can be marshalled to provide a range of benefits in an incremental manner.

Lean and the sustainability agenda (C726)

This guide shows how a Lean approach can support the areas of sustainability that you will encounter, making your role simpler and more effective.

Lean benefits realisation management (C727)

This guide attempts to build a clear and concise approach to description, measurement and delivery of lean benefits that is appropriate for Lean in a construction context.

A Lean guide for client organisations (C728)

This guide uniquely explains the principles behind 'Lean' and describes how to put them into practice from a client's perspective.

Selecting and working with a Lean consultant (C729)

This guide will help you assess what your organisation needs, identify potential consultants, procure their services effectively, have a productive relationship with them and develop your organisation's internal capabilities for the longer term.

Lean tools and techniques – an introduction (C730)

This guide outlines the use of Lean tools and approaches that have been adapted, developed and applied successfully in the construction industry throughout the UK and across the world. Several key tools are presented.

CITB

The CITB have recently funded a PhD at Loughborough – started in 2013 "Skilling the Construction Industry of Tomorrow".

The CITB is seeking to enhance understanding of the construction sectors labour supply side activity, specifically, the level and detail of training provision in the UK and how this maps on to demand side requirements both in terms of volume and quality. This information will provide an informed view of the adequacy and sufficiency of skills provision as part of the Sector Skills Council footprint and will inform overall decision making linked to the provision of construction-related training across the UK.

Wrap

Wrap's approach is focused on delivering resource efficiency. Their summary 2010 report "Securing the future – The role of resource efficiency" shows that implementing 13 quick win resource efficiency strategies (including Lean production) identified in 2009 could contribute as much as 10% of the target reduction in UK domestic greenhouse gas (GHG) emissions by 2020 as required by the Low Carbon Transition Plan. The 2010 report explores how these strategies could also reduce the UK's water use, reliance on specific materials and UK's ecological footprint.

They also have a series of documents exploring good practice in waste minimisation and management. The documents provide guidance for construction clients, design teams and contractors and include:

Achieving good practice Waste Minimisation and Management, how to minimise waste creation, improve waste management and recycling.

- Achieving effective Waste Minimisation this helps teams to reduce waste on their construction projects. It sets out what is meant by waste minimisation, why it is important, who should implement it and how it can be made an explicit requirement of the procurement process.
- Delivering good practice Waste Management provides best practice process guidance notes.
- Delivering effective Waste Minimisation provides practical and technical guidance on how to deliver against waste minimisation requirements (including lean). It covers communications, design, and planning and delivery during procurement and logistics phases.

Designing out Waste: a design team guide for Buildings / Civil Engineering. These documents provides information on the key principles that designers can use during the design process and how these principles can be applied to projects to maximise opportunities to Design out Waste. These are linked to a tool which provides a means by which designers can analyse the waste implications of their design decisions from an early stage in the project.

Academic papers

IR252-2b — A Guide to Construction Rework Reduction

In 2003, CII (Construction Industry Institute, Austin, Texas) identified and described the major factors related to rework potential, and formulated a self-assessment opportunity checklist to strengthen corporate construction quality processes to reduce field rework.

Efforts to reduce rework are still often impeded by a perception that rework is beyond the control of the contractor, or by a failure to implement a rework reduction program (RRP). RT 252 formulated the following guidance for addressing these issues:

- an explanation of how to deploy an RRP
- a top-ten list of rework reduction ideas
- innovative approaches to incentivizing rework reporting.

An RRP is first and foremost a measurement system for monitoring the magnitude and impacts of field rework.

"*A Rework Reduction Model for Construction Projects"* (2004) IEEE Transactions On Engineering Management , Vol. 51, No. 4, November 2004.

Develops an alternative procurement model for reducing rework in projects.

Project Pathogens: The Anatomy of Omission Errors in Construction and Resource Engineering Project (2009) Engineering Management, IEEE Transactions on Engineering Management (Volume:56 , Issue: 3)

Using data derived from 59 in-depth interviews undertaken with various project participants, a generic systemic causal model of the key factors that contributed to omission errors is presented.

Reducing rework costs in construction projects (2010) University of Twente, NL

This is a Bachelors degree which explores re-work and produces a model for capturing and codifying sources of re-work and makes suggestions for reducing the causes.

Barriers to implementing lean construction in the UK construction industry (2013)

The Built & Human Environment Review, Volume 6, 2013. Identifies 3 key barriers to the adoption of lean construction in the UK (mostly lack of understanding / commitment).

Reviewing the past to learn in the future: making sense of design errors and failures in construction (2013)

Structure and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance Volume 9, Issue 7, 2013. This paper examines the circumstances and issues that contributed to a series of construction and engineering failures to enable development of a learning framework that can be used to mitigate design errors and potential failures and accidents.

Design error management: interaction of people, organisation and the project environment in construction (2014) Structure and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance Volume 10, Issue 6, 2014.

Develops a systemic framework that classifies design error reduction and containment strategies according to people, organisation and project. It suggests that when people, organisational and project strategies are implemented in congruence then the propensity for design error reduction will significantly increase.

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