IMPROVING WORK FLOW RELIABILITY THROUGH QUALITY CONTROL MECHANISMS

Marton Marosszeky[1], Khalid Karim[2], Salinda Perera[3] and Steve Davis[4]

ABSTRACT

Lean construction relies on the distinction between value adding and non-value adding activities, and reducing workflow variability is one technique for reducing non-value adding activities. Planning controls such as the 'last planner' can go a long way in improving work flow reliability, but are limited in their capability to the extent they can expect the unexpected. The occurrence of specific defects in construction is, by the very fact of its happening, an unexpected event because whatever could be anticipated would be avoided. On the other hand, defects in construction have the compound effect of increasing work flow variability, as well as non-value adding activities in the form of rework. This paper explores two aspects of this problem, first of all a number of different tools were developed and trialed to explore their potential for improving defect avoidance, secondly the paper presents a generic analysis of the increase in rectification cost with time from an error being made. The paper outlines the implementation of trade start-up checklists; a management tool that was found to be particularly effective at improving quality outcomes on site.

KEY WORDS

Construction defects, Work flow variability, Time to rework, Defect incident record, Checklists

INTRODUCTION

Lean construction is about cutting waste and quality improvement was recognised as an obvious element early on (e.g. see the general performance model in Alarcón, 1997). Unreliable workflow results from variability in performance (Abdelhamid and Everett, 2002) and the whole aim of Last Planner is to shield work flow from uncertainty (Ballard, 1997). Defect rectification is not only 'waste' in itself but it can also impact on other trades, the project, and the end user in a number of ways. The magnitude of this impact depends a great deal on the timing of the discovery of the defect and the time it takes to commence and complete rectification. Koskella (1992) has alluded to poor detection and long cycle times to correction due to poor detection. An understanding of this impact will help in the determination of the 'total waste' and the savings that can be accrued. This will provide justification for allocating resources as a short-term cost to achieve long-term benefits, and encourage the industry to bear these costs. Furthermore, the greater depth of the process knowledge creates greater opportunities for improving the process.

This paper focuses on two issues, improving industry understanding of the full cost impact of defect discovery, management and rectification, as well as the development of short-term management strategies that enhance defect avoidance.

DEFECT STUDIES

The problem of quality in construction has been approached from a number of directions. These

1 Professor, Multiplex Chair of Engineering Construction Innovation, School of Civil & Environmental Engineering, University of New South Wales, 2052, Phone +612 93857773, m.marosszeky@unsw.edu.au

2 Lecturer, School of Civil & Environmental Engineering, University of New South Wales, 2052, Phone +612 93855163, k.karim@unsw.edu.au

3 Postgraduate student, School of Civil & Environmental Engineering, University of New South Wales, 2052, Phone +612 9385 4290, s.perera@unsw.edu.au

4 Lecturer, School of Civil & Environmental Engineering, University of New South Wales, 2052, Phone +612 93855052, s.davis@unsw.edu.au

include studies on standards based management system (see e.g. Seymour 1997, Al-Nakeeb 1998, Moatazed-Keivani et al. 1999), client led assessment systems (Pheng, 1999; Tam et al., 2000), the philosophy of Total Quality Management (TQM) in the form of factors affecting quality or the relationship between organisational performance and TQM (e.g. Shammas-Toma et al., 1998; Chan and Tam, 2000; Sharma and Gadenne, 2002), and studies focussing on defects. The last category includes investigating the apparent and root causes of defects and determination of the magnitude and cost of defect rectification or rework.

Josephson and Hammarlund (1999) undertook a detailed investigation into the causes and costs of defects on construction sites, and found the cost of defects ranging between 2.3–9.4% of the production cost. Hall and Tomkins (2001) not only determined the cost of quality failure but also quantified the delay cost in the form of additional resources expended to keep the project on schedule. This was estimated to be 19% of the failure cost and 1.1% of the project cost. They also noted a big jump in the cost of failure towards the end of the project, with latent failure being one of the main reasons. Josephson and Saukkoriipi (2002), however, noted the limitations of studies relating to quality costs and argued for the extension of these studies to eventually identify all visible and hidden costs.

Marosszeky et al. (2002) and Thomas et al. (2002) also quantified the cost of defects and, in the process, identified the generic structure of the waste loop created by current industry practice as shown in Figure 1. This is simply a depiction of the non-value adding activities that take place after discovery of a defect and gives no clue about the influence of the timing of the discovery. Furthermore, it was based on a study carried out during the fitout stages, by which time the defects caused by design and documentation problems have usually been sorted out. Nevertheless, it did provide the launching pad for investigating the impact of the time to rework by both highlighting its necessity as well as illustrating the range of the basic non-value adding activities that may take place within the rework loop. Figure 1 highlights the one partial and eight completely non-value adding activities as well as the fact that there is no feedback or learning and, consequently, no improvement.

TIME TO REWORK

The total 'visible' waste on account of defective work depends on the stage at which it is discovered and the time it takes to rectify the defect. The discovery of a defect may occur at the very first inspection of the subcontract supervisor, first inspection by the head contractor (HC), or any of the subsequent inspections by the parties involved, including the head contractor, the architect, the project manager, the client, and the end user. The worst case scenario would be where the defect is discovered by the end user because, notwithstanding the fact that it is the farthest in terms of time lapsed after the construction, this would usually be in the form of a component failure with consequences ranging from discomfort to disastrous. In this case the hidden costs of lost income and socio-economics costs described by Josephson and Saukkoriipi (2002) could also be quite significant but those are not the focus of this paper. It is believed that the hidden costs can be determined more accurately once the visible costs are spelled out in detail.

As far as the time to rectification (after discovery) is concerned, it is usually assumed that rectification would occur immediately after discovery. This is generally not the case, though when the discovery is by the immediate worker or their supervisor or immediately following trade this can be the case. The waste loop in Figure 1 gives an indication of the usual activities involved prior to rectification. This will take some time even if actions at each point are prompt, i.e. receipt of information is immediately communicated and acted upon at the earliest practicable time. In reality there may be delays at each point due to varying reasons, which will be discussed later.

Figure 1: Illustration of Rework Waste Loop

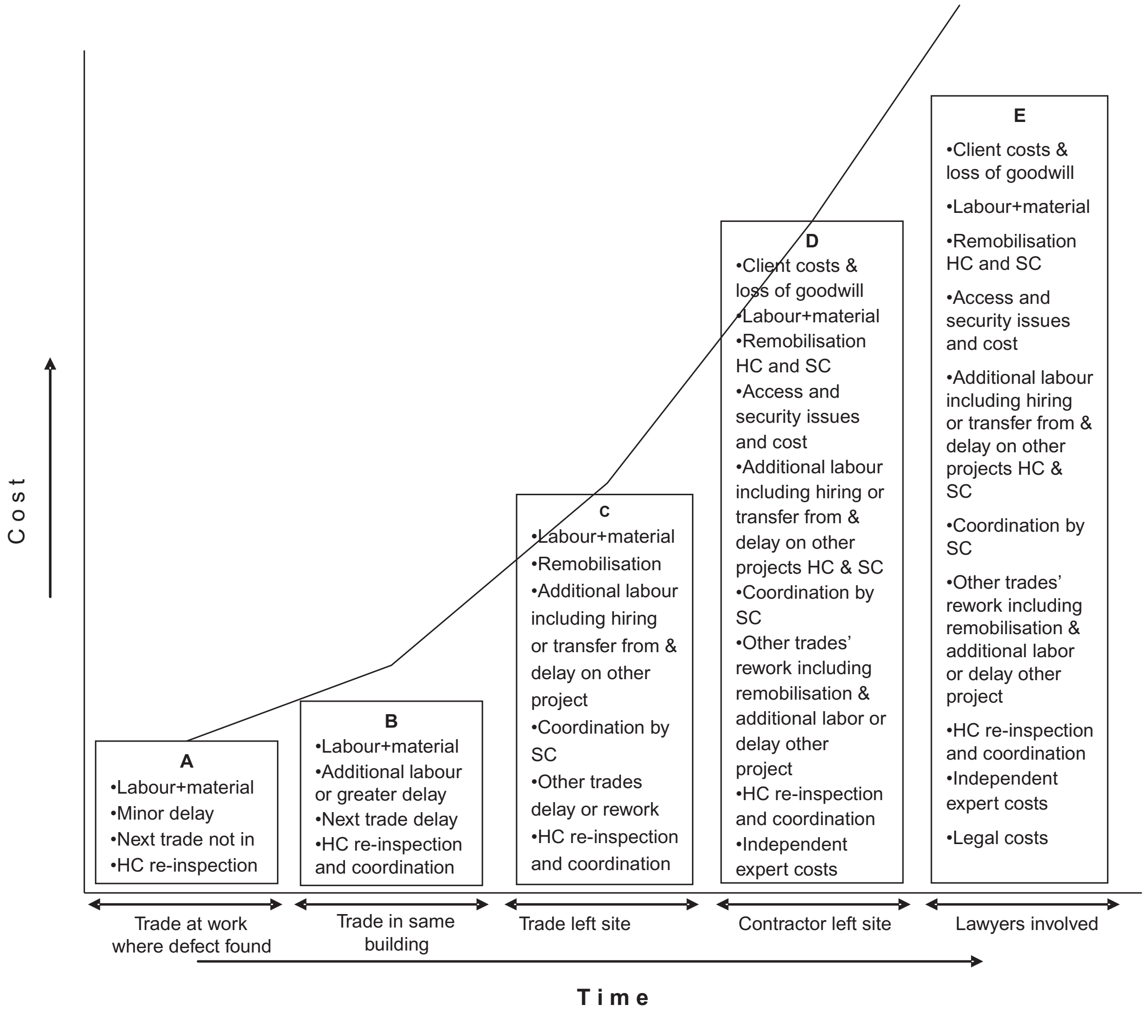

Figure 2: Notional Representation of The Escalation of Cost With Time After Defective Work

Time to Rework (TR) may be defined as the sum of the time to discovery and the time to rectification. The time to discovery is defined as the time lapse between the completion of work that is found defective and the point in time when it is noted to be defective. The time to rectification is the time between the discovery and the occasion when the rectification is signed off by all concerned. Figure 2 below illustrates the hypothetical TR cost curve and the activities that contribute to its increase over time.

As shown in Figure 2, it is anticipated that the increase in cost over time is not linear (it may be noted here that the curve or bars in the chart are not drawn to any scale). There are five primary stages when a defect may be discovered. The first stage (A) occurs while the responsible trade is still working in the vicinity where the defect has been found. In this case, the time to rework is quite short and the associated costs relatively low. The reason for this is that at this stage formal mechanisms do not need to kick in. In all likelihood, once the defect is observed, rectification is discussed with the concerned trade.

Furthermore, it would normally be through direct communication at lower levels of the hierarchy, such as the immediate supervisor and the worker or at the next level between the head contractor's foreman and the subcontractor's (SC) leading hand. In such circumstances, the action of rectification is also quite prompt and merely requires a minor diversion of resources in the same work area. At this stage, the subsequent trade has not yet moved into the work area and, therefore, the following activities are not delayed.

Things start to get more serious if the defect is discovered when the relevant trade has moved out of that work area, though it may still be in the same building. At Stage B, the non-value adding activities depicted in Figure 1 become part of the process. To start with, depending on the inspection regime, the defect may be discovered by any of the stakeholder parties except the end user. Furthermore the formal sign off process, as shown in the communication (of defect) and sign-off (of rectification) loop (Figure 3), may have commenced. The length of this loop depends on who discovers the defect. If the client or client's Project Manager (PM) discover the defect, then the communication will go all the way to the subcontractor and the re-inspection and sign-off will return by the same route.

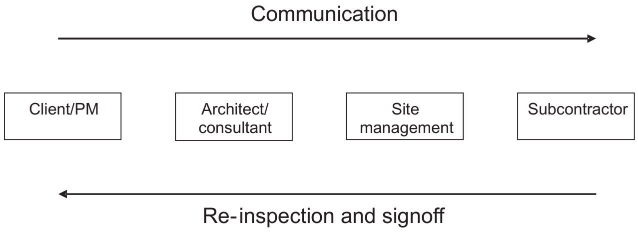

Figure 3: Communication Loop With Respect to Defects

At this stage, other cost centres also start to impact on the overall cost. The subcontractor has to plan rectification activities. These would involve either re-direction of labour from value adding tasks from the same or other projects, or hiring additional resources. The former would involve delays for the subcontractor, while the latter would involve different operatives performing the task of rectification. Furthermore, at this stage subsequent trade(s) would already have moved in and not only would they be delayed but the HC would also be required to coordinate between the subcontractors. The HC may even have to initiate alternate design documentation to remedy the problem.

Stage C relates to discovery of defect when the builder has left the site. This would include all activities mentioned previously but at an increased cost. Furthermore, at this stage the subcontractor has to remobilise his workforce and this needs greater coordination and the subsequent trade(s) will often need to return to the site to do rework as well. Similarly, at Stage D when the users have taken occupancy, all previous costs are present at an increased magnitude and there is additional cost of remobilisation of the subcontractor, and independent experts have often been involved.

The worst case scenario is represented by Stage E, once lawyers have been involved in the process and a number of years have passed due to inability of the parties to resolve the way forward. Not only does this require remobilisation of all relevant parties, costs in the form of experts' fees and legal costs rapidly escalate the costs and resolution is usually costly and slow. The previous scenarios have assumed that each party has accepted its liabilities. If this does not happen, then the dispute resolution loop is also introduced and the burden of legal and expert costs can be quite significant.

The hypothetical relationship illustrated in Figure 2 can be fully defined and costed with the help of detailed information relating to defects occurring on construction projects. However the components of the costs will vary from case to case and the variation in costs can be considerable. This information would include the time to discovery and rectification, as well as information about the following cost elements:

- the direct labour and material costs
- the indirect costs of the subcontractor in organising the rework
- head contractor direct and management costs
- delay costs for the project including delays to the concerned trade as well as other trades
- design, documentation and reinspection costs by third party professionals
- consequential damage caused by the failure, for example damage to carpet and finishes by leaking water
- the cost of expert reports by the various parties
- the legal cost of the parties
- the opportunity costs of the parties involved in the organisation and execution of the rectification

This level of information is rarely available or sought, even when the latest IT based defect management systems are being used, and when it is available it is rarely compiled. To research the causes of defect occurrence further a 'Defect Incident Record' (DIR) has been designed and implemented on sites to obtain more detailed data at the site level. Meanwhile, a typical example has been constructed on the basis of previous problems the authors have examined to explore the relationships illustrated in Figure 2 further.

CASE 1—BATHROOM WET AREA LEAK IN A MULTISTOREY TIMBER FRAMED CONSTRUCTION.

This building was a mid rise refurbishment and change in use. In this case, because water was leaking around bathtubs and from under showers, through the timber structure to the floor below and because of a conservative design of the rectification, the entire bathroom floor membrane was renewed.

- Cause of failure—defective waterproof membrane application and detailing during construction
- Time of discovery—after the end users had taken occupancy, construction plus 12 months
- Time of rectification—construction plus 5 years
- Cost of rectifying during construction ~$150 allowing for additional materials and labour
- Legal costs per bathroom (assuming 50% of total), (both parties) ~ $1,000
- Costs of expert reports, design and supervision, (assuming 50% of total) pro rate per bathroom ~ $1,000

Figure 4: Table Showing Estimated Increase in Costs for Repair of Leaking Shower Recess Waterproofing

	Indirect						Direct			TOTAL	
	inspect	test	experts	legal	admin	Total	labour	matrls	Total	**All up**	
A Immediate recification	20					20	50	20	70	**90**	
B Picked up in test after tiler has moved on to another bathroom	75	50			75	200	300	150	450	**650**	7
C Picked up after leaving site, HC test	300	50			150	500	600	150	750	**1250**	14
D Picked up after owners have moved in, immediate rectification	450	50	600		300	1400	800	150	950	**2350**	26
E Picked up after owners have moved in, insurance and legal dispute involved	750	50	1200	1200	450	3650	800	150	950	**4600**	51

Assumptions

- *The labour cost is $50 per hour and supervision $75 per hour, independent experts cost $200*
- *The expert and legal costs assume approximately 20 units, these costs are extremely variable, if there are 100 units these costs will will reduce per unit, though not significantly as with larger buildings disputation often increases*

- Direct cost of stripping out bathroom and re-applying waterproof membrane to entire floor ~ $15,000
- In kind cost from voluntary work of members of the owners corporation (assuming 50% of total) ~ $500
- Total rectification cost ~ $17,500
- Ratio of rectification to initial avoidance cost >100 to 1

CASE 2—BATHROOM WET AREA LEAK IN A MULTISTOREY CONCRETE FRAMED CONSTRUCTION

This building was a new town house and tower construction with some 200 dwelling units. In this case the waterproofing of the shower recess was poorly executed and water migrated on top of the slab under walls damaging carpet and paint on the other side. More than 50% of the bathrooms had similar problems.

- Cause of failure—defective waterproof membrane application and detailing during construction
- Time of discovery—after the end users had taken occupancy, construction plus 12 months
- Time of rectification—construction plus 7 years
- Cost of rectifying during construction –$90 allowing for additional materials and labour
- Legal costs per bathroom (assuming 50% of total), both parties ~ $750
- Costs of expert reports, design and supervision, (assuming 50% of total) pro rate per bathroom - $750
- Direct cost of stripping out bathroom and re-applying waterproof membrane to entire floor $650
- In kind cost from voluntary work of members of the owners corporation (assuming 50% of total) - $500
- Total rectification cost - $2,150 cash plus $500 in-kind
- Ratio of rectification to initial avoidance cost >20 to 1

Figure 4 gives a typical indication of the manner in which the costs escalate with time and with the stepwise escalation of the disagreement between the parties. It is hard to imagine how any contractor can do other than focus on avoidance when these figures are viewed.

MANAGEMENT TOOLS FOR DEFECT AVOIDANCE

Two quite different management tools were developed to asses their potential for improving defect avoidance, these were trialed on a number of construction sites. The first of these were checklists at the handover between trades to create a greater focus on trade responsibility and customer - service provider relations, the second was a defect incident record to facilitate the early recognition and subsequent avoidance of construction errors.

HANDOVER CHECKLISTS

As a follow on from the previous study (Marosszeky, et al. 2002; Thomas et al. 2002), the idea of checklists was introduced as an interim control measure in an attempt to ensure that most, if not all, defects are detected and rectified before Stage B (Figure 2). When the idea was initiated on sites, it was discovered that the quality management systems of all builders already contained checklists, generally these were a contractual requirement from the head contractor to the sub-contractor and formed a part of the contractual quality system. These generally needed to be signed off as a part of the contract, however they were used as a contractual device rather than a process management device. Consequently, it was proposed that a simplified checklist be designed as a process tool at the handover. Initially it was suggested that this checklist be completed by the trade handing over a particular area, and it was suggested that the signed checklist be agreed to by the following trade or by the head contractors representative, whichever was more appropriate. However, it was argued by both builders and subcontractors that it was unlikely that a trade would acknowledge its own defects and the exercise would be rendered meaningless. More to the point, the proposed instrument clashed with the existing checklists mandated by the contractual system, duplicating the checklists already in place.

Furthermore the suggestion that a checklist be checked off by the following trade before the commencement of their work was found to be complicated because some subsequent trades had to check the work of several preceding trades. For example, a painter moving into a new area would need to check off the signed checklists of the plasterer, electrician, joiner and in some instances the plumber as well. This would have been impractical. Consequently, the idea evolved to design a 'trade start-up checklist', which required a trade to fill in a checklist that identifies quality problems in any preceding work that could affect their work before they start in a new area. Hence a typical checklist for the renderer could include items like the brickwork being plumb, door frames properly aligned, wall and area clean, and clear access to the work area while for a tiler, this may include items like the waterproofing being complete and acceptable for tiling, plumbing fittings correctly installed, clear access, necessary drawings and requirements from other services being available, etc. The interesting novelty in this approach was that this was a new process and in fact it represented the immediate customer of the preceding works assessing the quality of the work being handed over.

The whole process of developing and, more importantly getting it implemented on site, took much longer than initially envisaged. The barriers encountered during the process were not dissimilar to those identified in other studies. These included

- *Resistance to change*—there is a general culture of resistance to change, with very little learning within and across projects.
- *Management attitude*—there is a distinct tendency, in most cases, to exercise authority rather than leadership. This undermines the

LOGO
Issue 1
Amendment A

Trade Commencement Checklist

Work Area……………………..

Plumber

DESCRIPTION	INITIAL	COMMENTS	BUILDER COMMENTS
Joinery details match bathroom details			
Tiler protect FW from sand cement.			
Renderer avoided sand & cement in FW.			
Tiler has set floor to 1m mark as per everyone else.			
Rooms lockable and secure to prevent theft.			
Work area left tidy and accessible by the preceding trades			

Dated…………

Figure 5: Trade Startup Checklist

spirit of teamwork so necessary for the improvement of quality.

- *Resistance to paperwork*—even simple one page checklists are seen as unnecessary paperwork, primarily because they are not seen in relation to the larger problems they are trying to avoid. They are seen as something that inhibits progress and a part of the HC's bureaucratic risk management strategy rather than a tool for process improvement.
- *Language difficulties*—a considerable proportion of trade workers are from a non-English speaking background and hence they either have difficulty in understanding and completing the checklists, or use it as an excuse.

Figure 5 illustrates a sample checklist developed by the plumbing trade. The trial of these checklists on a small project has been recently completed. There was general consensus among the head and subcontractors that the use of these checklists significantly reduced the occurrence of defects on the project. In the words of a Director of the HC firm, "the architect is finding it quite difficult to identify any defects on the project". The reasons for this improvement are discussed in more detail in the conclusion.

DEFECT INCIDENT REPORTING

The development and implementation of the Defect Incident Record (DIR) was initiated to regulate the exchange of information between the researcher and the site. The idea was to create a simple record on site to capture the occurrence of quality errors when they occur, and to communicate these to the researcher for later follow up.

It had been planned that the researcher would call in to the site once or twice a week and investigate the causes of the errors that had been recorded by questioning those who were involved with the defective work. It was hoped that this would lead to the identification of root causes and the development of ideas for improvement and avoidance.

The simple structure of the form used is illustrated in Figure 6, it was to be filled in by head contractor supervisory staff at any time during the working week when a defect was identified.

In reality these documents rarely served a greater purpose that the simple capturing of defects and notifying them to the research team and hence they did not live up to the research teams' expectation. It has been found in this and in previous research that it is difficult to engage in deeper analysis such as root cause analysis on a construction site. The culture does not run deep enough to create the opportunity for such a basic analytical approach and the politics between different subcontract firms often preclude real honesty.

On a number of sites contractors invested in PDA based defect collection technology part way through the project. In most instances this was used simply as the automation of the defect related data collection. It was observed was that in fact the PDA based systems, while they automated record keeping and thus added some efficiency, did nothing to motivate early problem recognition and reaction. Hence the finding was that there is a need to distinguish between record keeping per se and the idea of early identification, rectification and avoidance.

CONCLUSION

This paper reports two aspects of recent research into the area of defect avoidance and the cost of defects in building construction. The first finding demonstrates that the cost of defect rectification increases rapidly as the time from error creation to rectification increases. In the case of a defective waterproofing membrane, this cost ranges up to 50 or even 100 times the initial cost if the problem had been rectified during construction. For contractors this should indicate the utter folly of neglecting quality management measures that ensure the avoidance and elimination of defective work as early as possible and certainly within the contract period.

Site………….			Amendment A **Defect Incident Record**			Issue 1
Location/Area	**Defect**	**Trade**	**Date Identified**	**Date Rectified**	**Original completion**	**Cause**

Figure 6: Defect Incident Record

The second theme explored is the development of tools to improve defect avoidance throughout a project. The first of these was a trade start-up checklist, the second a defect incident report. The paper describes several strategies that were explored to increase the focus on the trade handover. This was an issue that arose out of previous work by the same research team (Marosszeky et al, 2002) where it was argued that defects have to be found at source and repetition avoided through motivation and tools that bring a focus on the trade handover. Interestingly, the use of the trade start-up checklist was found to lead to a significant improvement in defect avoidance. The use of this device focused attention of workers on the site on the supplier—customer nature of the relationship between trades and led to significant improvements in quality.

The second management tool that was explored was a simple device called a Defect Incident Record to log new and significant incidences of defective work. This simple tool, which was conceived of to form the basis of the communication between the site and the research team but was found to have limited additional benefit, apart from simply logging defects when they occurred and communicating them to the research team, or to any data collection process for that matter.

Initially it had been hoped that this process would create a focus of problem analysis and avoidance and this in turn would lead to improvements in quality. This was not found to be the case. It was also found that the use of PDAs to create error lists do not of themselves add to the goal of achieving greater focus on problem identification, resolution and avoidance. They are generally used as a simple device for automating a labour intensive process, the recording and transcribing of defect data. As such, they have their place but are no substitute for an increased focus on error detection and avoidance.

ACKNOWLEDGEMENTS

The authors acknowledge the support of an industry consortium comprising the following companies: Management consultants Farrell Management, Head Contractors Barclay Mowlem, Baulderstone Hornibrook, Mainbrace, Multiplex, Reed Constructions and Walter Construction, and specialist contractors and designers Acoustic Logic, Ajax Plumbing, Cubic Interiors, De Martin Gasparini, Fugen, Hastie, Kone, Polyseal, Star Electrical, Team Members, Waterman AHW. These contractors both funded the research and provided access to the research team on their sites.

REFERENCES

Alarcón, L. F. (1997). Modeling waste and performance in construction, *Lean Construction* (Ed: Luis Alarcón), A. A. Balkema, Rotterdam, 51–66.

Abdelhamid, T. S. and Everett, J. G. (2002). Physical demands of construction work: A source of workflow unreliability, *Proceedings 10th Conference of the International Group for Lean Construction* (Ed: Carlos T. Formoso & Glenn Ballard), Federal University of Rio Grande do Sul, Brazil, 87–100.

Al Nakeeb A., Williams T., Hibbered P., and Granow S. (1998). Measuring effectiveness of quality assurance systems in construction industry, *Property Management*, **16** (4), 222–228.

Ballard, G. (1997). Lean construction and EPC performance improvement, *Lean Construction* (Ed: Luis Alarcon), A. A. Balkema, Rotterdam, 79–92.

Chan P.C. and Tam C.M. (2000). Factors affecting quality of building projects in Hong Kong" *International Journal of Quality and Reliability Management*, **17** (4/5), 423–441.

Hall, M. and Tomkins, C. (2001). A cost of quality analysis of a building project: towards a complete methodology for design and build, *Construction Management and Economics*, **19**, 727–740.

Josephson, P. E. and Hammarlund, Y. (1999). The causes and costs of defects in construction: A study of seven building projects, *Automation in Construction*, **8**(6), 681–87.

Josephson, P.-E. and Saukkoriipi, L. (2002). Non value-adding activities in building projects: A preliminary categorisation, *IGLC 10*

Koskella, L. (1992). *Application of the New Production Philosophy to Construction*, Centre for Integrated Facility Engineering, Technical Report 72, Stanford University.

Marosszeky M., Thomas R., Karim K., Davis S. and McGeorge D. (2002). Quality Measurement tools for lean production from enforcement to empowerment, *Proceedings 10th Conference of the International Group for Lean Construction* (Ed: Carlos T. Formoso & Glenn Ballard), Federal University of Rio Grande do Sul, Brazil, 87–99.

Moatazed Keivani R., Ghanbari Parsa A. and Kagaya S., 1999, "ISO 9000 standards: perceptions and experiences in the UK construction industry" *Construction Management & Economics*, 17, 107–119

Pheng, L. S., Kee, B. T. and Leng, A. A. A. (1999). Effectiveness of ISO 9000 in raising construction quality standards: some empiri-

cal evidence using CONQUAS scores, *Structural Survey*, 17(2), 89–108.
Seymour D. (1997). Assessing quality control systems: some methodological considerations, *Lean Construction* (Ed: Louis AlarcÓn) A.A. Balkema, Rotterdam, pp. 437–456.
Shamms –Tomma M., Seymour D. E. & Clark L. (1998). Obstacles to implementing total quality management in the UK construction industry, *Construction Management and Economics*, 16, 177–192.
Sharma B. and Gadenne D. (2002). An inter industry comparison of quality management practices and performance" *Managing Service Quality*, 12 (6), 394–404
Tam, C. M., Deng, Z. M., Zeng, S. X. and Ho, C. S. (2000). Performance assessment scoring system of public housing construction for quality improvement in Hong Kong, *International Journal of Quality & Reliability Management*, 17(4), 467–478.
Thomas R., Marosszeky M., Karim K., Davis S. and McGeorge D. (2002). The importance of project cultures in achieving quality outcomes in construction, *Proceedings 10th Conference of the International Group for Lean Construction* (Ed: Carlos T. Formoso & Glenn Ballard), Federal University of Rio Grande do Sul, Brazil, 101–113.