For inclusion in an ARCOM Conference Issue guest-edited by Simon Smith: The role of the supply chain in elimination and reduction of construction rework and defects: an action research approach

Journal:	*Construction Management and Economics*
Manuscript ID:	RCME-SI-13-0187.R2
Manuscript Type:	Paper for a Special Issue
Keywords:	Action research, Defects
Keywords (user-entered):	Rework, Snagging, Supply chain collaboration

Author responses to referees' comments

We ask authors to explain how they have responded to referees so that the referees can judge the extent to which their comments have been taken on board. It is not expected that all referees' comments can or will be incorporated into the paper, especially when the referees have made conflicting comments. Some authors may choose to provide their rebuttal in their response to referees, rather than by modifying the paper. Referees are encouraged to acknowledge that they may simply hold a different view, and that disagreement between authors and referees does not necessarily signal a weakness in a paper. As with the primary round of refereeing, please focus on the strength and validity of the research and findings, rather than on spelling and grammar. Our copy editors can deal with the English if the paper goes forward.

Dear Professor Hughes,

Thank you for your email as above, in response to this I have made the following changes:

1 - Deleted the abbreviation explanation for UK

2 - Extended CSO and SCSI fully in the citations and reference list. DKN economic consultants trade as DKN and use no extended version of their name so I have left this as per the original.

2A- I have added back in the "Author" reference details to Citations and References list as instructed.

3- I have tried to find printed versions of Comit (2007); CSO (2013) and Ulster Bank (2013) but they appear to be only published in database / electronic form. I have thus shortened the links using goo.gl as suggested. All three are from respected sources.

3A - Was unsure of the "News items as authoritative sources" as I don't think I used any newspaper or magazine type references in the paper? On second reading I thought you were possibly speaking generally? As it appeared in the comment on URLs I would confirm that Comit (2007); CSO (2013) and Ulster Bank as well as DKN Economic consultants are all references from fairly reliable sources presenting either Government Statistics or Periodic reports of some standing.

Apologies if I have misunderstood what you require in 3A, if you have any specific concerns please let me know ASAP and I will do my very best to speedily address them.

Kind regards

The Authors

THE ROLE OF THE SUPPLY CHAIN IN THE ELIMINATION AND REDUCTION OF CONSTRUCTION REWORK AND DEFECTS: AN ACTION RESEARCH APPROACH

Abstract

Since 2007, Ireland has suffered a circa 80% reduction in construction output. This has resulted in bankruptcy, unemployment and bad debt. Contractors have attached greater emphasis to production efficiency and cost reduction as a means of survival. An Action Research (AR) strategy was used in this research to improve processes adopted by a SME contractor for the control of defects in its supply chain. It is conservatively estimated that rework, typically accounts for, circa 5% of total project costs. Rework is wasteful and presents an obvious target for improvement. The research reported here concerns the (first) diagnosing stage of the AR cycle only, involving: observation of fieldwork, analysis of contract documents, and semi-structured interviews with supply chain members. The results indicate potential for supply chain participants to identify root causes of defects and propose solutions, having regard to best practice to avoid re-occurrence. A lack of collaborative forums to contribute to production improvement was identified. Additionally the processes, used to collect, manage and disseminate data were unstructured and uncoordinated, indicating scope for developing more efficient methods. The research indicates good understanding of the potential benefits for supply chain collaboration but suggests that the tools and knowledge to collaborate are currently lacking in the SME sector.

Keywords: action research, defects, rework, snagging, supply chain collaboration

Introduction

The construction industry tends to renew its focus on improving production processes, towards removing waste, during times of austerity. Koskela *et al,* (2012) trace the historical interest in production waste to the start of the 20th century noting, that it has never been a prevalent concept in construction management or indeed management literature generally.

In times of high demand, building contractors are able to neglect build quality to some extent, in the rush to completion. Thereafter they either avoid remedial works or mask the consequences of rework behind higher profit margins (Sommerville *et al,* 2004). The Barker review on UK housing supply, published in 2004, noted that contractors did not have to deliver a particularly good finished product to secure market share.

The research reported here was carried out in the Republic of Ireland (Ireland), but should be of value in other jurisdictions. For a number of reasons, including geographical, historical and linguistic the construction production processes used in Ireland are similar to those of the UK (Thomas & Hore, 2003). This research reports results from the diagnosing (stage one) and preliminary consideration of action planning (stage two) of an AR improvement project involving an SME building contractor. It is intended that the remainder of the AR cycle be reported in future papers.

Ireland suffered a severe economic downturn in 2007. Construction has borne a disproportionate part of the burden in terms of bankruptcy, debt and unemployment. Construction output (Base line figure 100 in 2005) rose to a peak of 106.2 (Q2 2007) and has collapsed to 23.6 (Q1 2013) a decline approaching 80% (Taggart *et al*, 2012; Central Statistics Office Ireland, 2013). Prior to 2007, the industry was at the forefront of a property led boom, although its predominance, at 24% of GNP was seen as unsustainable by many commentators (DKN economic consultants, 2009; Kelly, 2009). The industry is currently undertaking a painful adjustment, shedding over half of its workforce and also adapting to a new reality, with tender prices having reduced by circa 28% from peak (Society of Chartered Surveyors Ireland, 2012). Some optimism has returned in 2013, with the Ulster Bank Construction Purchasing Managers index reporting raised orders and the highest optimism since 2007. Employment and current activity are still, however, falling marginally (Ulster Bank, (2013).

In response to this environment, contractors focused on lowering tender costs to increase workload. Weaker companies resorted to below cost bidding as a survival strategy (Society of Chartered Surveyors Ireland, 2012). Davis Langdon (2011) reported that this practice is now moderating and some stability has returned to pricing levels.

Defects are discovered at many stages of production: - during construction, during terminal inspections, after the project has been handed over, or, in the subsequent maintenance period (Love & Edwards, 2004). The particular focus of this research concerns defects discovered at or near the end of construction projects. Rotimi *et al*, (2011) define these defects as *'snags'* and the process of identification and rectification as *'snagging'*. These terms are readily used and understood within the industry, but do not appear with any prominence in the literature (Sommerville *et al,* 2004).

The research is justified, by reference to the costs involved. The available literature suggests a figure of 5% of total project cost could conservatively be attributed to rework and defects. Hwang *et al*, 2009 suggests such a percentage for the United States of America and Love, (2002) applied similar percentages in Australia, both generating frightening results in terms of the amount of money being wasted. Applied to Ireland, such a percentage would mean circa

€1.89 billion (2007) was wasted at the peak of the recent boom. In more challenging times (2012) a figure of circa € 375 million applies. Economic consultants DKN, (2011) suggest that the industry will recover to sustainable levels over the medium-term, suggesting that waste associated with rework and defects may likewise 'recover' to circa €850 million per annum in the medium-term.

Research aims and participants in the research

The purpose of the research and empirical work described herein was twofold. Firstly to assist a Small / Medium enterprise (SME) to improve its productive processes towards the elimination / reduction of rework and defects. Secondly the work seeks to contribute to theory in the area of defects elimination and management through dissemination of the research findings (Baskerville, 1999; Robson, 2000). This involved work in the following areas: (1) understanding and improving their defects identification and management systems. (2) providing an understanding of the costs involved (3) providing root cause analysis into defects toward the avoidance of future repetition, and; (4) training and learning.

The construction company involved in the study is a regional SME established in business over 15 years. The company was driven by its managing director and flourished during the boom, but now, like others, finds itself in reduced circumstances in terms of turnover and workload. The company is engaged in industrial, commercial, public works and bio-medical projects. Using EU recommendations on the classification of companies (EU 2003/361) the company is classified as *'small'* less than 50 employees, less than or equal to €10 million turnover and less than or equal to €10 million balance sheet.

Research strategy – Action research

Action Research is a pragmatic research strategy since at its core is the epistemological paradigm that the 'truth' to be found is based upon the utility of the research (Anzar *et al*, 2010). It is a powerful tool for researchers who are interested in finding out about the interplay of humans, technology, information and social-cultural contexts (McKay & Marshall, 2001). AR seeks to address some of the deficiencies found in traditional research approaches in regard to relevancy. Traditional research has tended towards descriptive and explanatory approaches, somewhat at the expense of more prescriptive knowledge, having direct relevance to industry (AlSehaimi, *et al*, 2013). AR also involves the adaptation of new approaches or practices to empirical circumstances (Altrichter *et al*, 1996; Bresnen & Marshall, 2001). This is essentially, the goal of this research.

AR seeks to contribute to the practical concerns of people in problematic situations whilst contributing to scientific knowledge in a collaborative effort (Rapoport, 1970; Holt & Lennung, 1980; Baskerville & Myers, 2004). This stance is supported by Susman & Evered, (1978) who additionally suggest that AR should develop the self-help competencies of problem-solvers within organisations. AR typically involves a *'cycle'* or *'spiral'* of five project stages (Susman & Evered, 1978). (See figure 1). These stages entail: - (1) diagnosing, involving identification and defining the scope of the problem; (2) action planning, which requires consideration of alternative actions for addressing the problem; (3) action taking, which involves implementing an improvement plan (4) evaluating, which requires study of the consequences of the actions; and (5) specifying learning, which is used to identify findings and suggest improvements for further iterations of the cycle.

AR combines data generation from a social system with an intention to provide positive change. Lewin (1947) noted that the most important factor in social science should be to practically contribute to the change and betterment of both society and its institutions. The AR research strategy is founded on five tenets: (1) having clear goals and a commitment to values; (2) contextually focused; (3) the explanation of research materials concerning the changes; (4) active researcher participation in the process; and (5) the dissemination of the research (Elden and Chisholm, 1993). AR promotes organisational change, towards the betterment of participants, as well as the normal research outputs of description, understanding and explanation (Robson, 2000).

Research methods

Given the nature of AR, a substantial amount of diverse qualitative data was produced. A flexible design approach was selected to manage the data. It is difficult to disaggregate the multiple and interactive causes of defects in any meaningful way or relate them usefully to objective features of the context. Thus the research strategy adopted here, allows the problems to be considered holistically (Shammas-Toma *et al,* 1996; Seymour *et al,* 1997). A literature review was conducted to build up knowledge of the problem. Firstly, in the area of construction supply chains focusing on collaborative working practices and secondly in the area of construction rework and defects. The supply chain literature is extensive and the defects literature more modest. Sommerville *et al,* (2004) reported that snagging data and the snagging process itself have rarely been written about in the UK. A field study took place on one of the SMEs projects to assess in detail how they managed rework and defects and to gather data about the root causes of the problems they encountered.

The field researcher (author 1) spent time (typically one half day per week) over a four month period on the project, and *'participated'* in the process of snagging data as a participative observer (Vinten, 1994; Gill and Johnson, 2002). This participation included unstructured observation and photographing of activities (Mulhall, 2003). Semi-structured interviews were conducted with a broad cross section of project participants to gain understanding of their opinions and to understand the context, with a view to enabling change (Robson, 2002). Interviewees included architect, services designers, contracts director, site manager, sub-contractors and material suppliers. Additionally, informal conversations with site operatives took place and were summarised and recorded, in field notes. A final means of data gathering was to collate and analyse the documented parts of the snagging process used on the project. This included copies of drawings and specifications, programme, requests for information and terminal snag lists. The research was open and transparent. Posters were placed on site explaining who the field researcher was and his intentions. Stakeholders were free to engage with the research or not as they saw fit (Denscombe, 2010).

Definitions

The term 'rework' describes work that has to be done for a second time. This results from a variety of errors in execution, but also from client led changes (Love and Edwards, 2004). If the defect is caused by the former it is unlikely the contractor will be paid for rectification, but if the cause is the latter they may be entitled to contractual recompense. Love and Edwards (2004) define rework as;

> *'Unnecessary effort of re-doing a process or activity that was incorrectly implemented the first time'*

This definition is not entirely satisfactory as it can be seen that, in the context of some client led changes for instance, the original work may have been implemented correctly, but is now redundant. Thus at a holistic project level it may well have been unnecessary, without necessarily, having been implemented incorrectly. Likewise; Hwang *et al,* (2005) suggest:

> *'Rework is the process by which an item is made to conform to the original requirements by completion or correction'*

Again, in some circumstances the item may well conform to the original requirements but must still be changed for some reason. Rework is clearly repeat work, but its definition must and can only be considered in the particular contractual contexts that apply. From the contractor perspective it is often a question of whether they will be paid for the rework. Shammas-Toma *et al,* (1996) clearly noted that interview discussion on causation of defects in their studies was coloured by an awareness of contractual liability.

The focus here concerns defects identified and remediated at or around the end of projects commonly known in industry as *'snagging'* but a term not often found in the literature (Sommerville, 2007). Other terms used with a similar meaning to snag include faults, repairs, quality failures, deviation, non-conformance and rework. Often these are used interchangeably with the same or similar meaning (Sommerville, 2007; Rotimi *et al*, 2011). Precise, agreed definitions in the area of defects and snagging are absent (Georgiou *et al,* 1999; Iiozor *et al,* 2004).

Defects Causation

A number of contributions reflect on root causes of defects with a general consensus that cause usually lies deeper than a superficial blaming of construction operatives and managers (Atkinson, 1999), albeit that in some cases they are contributors. Broad agreement is found on a common core of practical causes, others explore more theoretical contributions. Sommerville (2007) evaluated work by the Building Research Establishment (BRE), to identify defect causes. This assigned cause to three broad headings: design issues (50%); construction phase issues (40%) and product failures (10%). Josephson *et al,* (2002) looking at similar areas suggested: design related causes (26%); site production / process (20%); workmanship (20%); materials failure (17%); client issues (6%) and machinery failure (3%). The causation headings are similar, but the allocation of cause is not. This is possibly related to different definitions, conceptual frameworks and models. The influence of design errors (as illustrated above) on defects that occur later in the supply chain is well considered in the literature. Design errors are diverse in nature and in the severity of their impact (Lopez *et al,* (2010). Influencing factors on the propensity of design errors include, unrealistic design programmes, organisational culture, lack of quality assurance practices, inadequate scoping of client needs and lack of a common language, with which to articulate client wants (Lopez *et al*, (2010).

Love *et al*, (2009) produced a list of 29 possible rework causes. These are loosely categorised as (1) scope changes; (2) erroneous design / documentation; (3) lack of quality management systems and; (4) poor workmanship. Mining into these headings, a number of factors are prominent including; (1) misinterpretation of drawings and specification; (2) use of superseded drawings and specifications in the supply chain; (3) Poor or imprecise communications; (4) lack of supply chain co-ordination; (5) poor training and skill levels and; inadequate supervision (Chong and Low 2005).

Love *et al*, (1999) discussing the work of Shewhart (1931) in a construction context, suggests two root cause factors of defects: firstly, those that originate because of problems in the production process, termed common causes, for example poor information flow between supply chain participants. Secondly, special causes that arise outside the production process, beyond the contractor's immediate control, e.g. unilateral client changes. They suggest that 85% of all construction rework emanates from the former and only 15% from the latter (Love *et al*, 1997).

Atkinson (1999) found commonality with others in areas which he terms *'primary'* and *'managerial'*. These cover causation themes discussed previously. He extends the debate to consider the impact of *'global'* factors such as organisational culture, economic pressures and societal pressures as contributory root cause. Returning to this theme in 2002, he found a predominance of managerial root causes, albeit with a significant contribution from global factors (Atkinson, 2002). Shammas-Toma *et al,* (1996) in a similar vein, differentiate between defects which appear during construction, but are caused by the supply chain, prior to construction (such as design). These are termed 'management controllable'. A second category concerns defects occurring at the point of production, termed 'operative controllable'. The authors note that most quality systems they observed in the field are only capable of detecting the latter.

Josephson & Hammarlund, (1999) took a broader look at causation in a longitudinal study of seven major projects. They note that motivation to produce good work is insufficient and that operatives must also have the necessary knowledge and information to execute the task correctly. In many cases this was lacking. They noted several factors that contributed to higher defect levels, including; (1) delays in decision making by clients; (2) late end user involvement; (3) contractual pressures in terms of cost and time. Conversely they also note some disarmingly simple factors that tend to limit defect levels: (1) stability in the client and design team composition; (2) previous experience of working with project participants; (3) supportive project management, leading to; (4) higher motivation.

Love *et al,* (2009) suggested that underperformance (such as having high defects) is often explained away as an unusual aberration by participants. This is because they do not wish to draw attention to such an unpalatable situation, lest they be harshly judged by customers and others. The cost of such non-conformance can drastically increase costs and impact on profit margins. Rooke *et al*, (2004) notes practices, whereby contractors manipulate poor design and specification for commercial advantage. The authors reported on the strategy of bidding low to win projects which they perceive as having a high probability of delays and claims. This extended to anticipation of poor design that would prove impossible to execute and manipulating programme to maximise the chances of delay. Opportunity for such practices is dependent upon procurement and contractual arrangements. The authors noted that such practices increase in times of austerity.

Construction companies tend to rely on the practice of identification of defects during interim and terminal inspections. This is often driven by formal quality systems. This approach however deals with the symptoms, whilst root causes remain hidden (Shammas-Toma *et al,* (1996). Eradication of root causes provides a long-term solution to the problem of defects. Seymour *et al*, (1997) agrees with this proposition. They note that companies engage in 'firefighting' what they perceive to be sporadic defects, when in fact they face chronic defects. Little attention is given to understanding and eliminating the latter. The cost in prevention measures is usually minimal when compared to the costs of rework, scrap materials and lost time (Abdul-Rahman, 1996).

Cost of rework and defects

Whilst there is some consensus in the literature concerning causation, the literature on the costs of rework and defects is very fragmented. A wide range of suggested cost estimates are allied to a number of disparate models for calculating costs. These models all have differing variables as to what should be counted. No obvious standard approach is found in construction (Fayek *et al,* 2004). Almost all of the cost estimates found are expressed as a percentage of the Total Project Cost (TPC). The defects found in snagging are generally attributable to specific contractor organisations and individuals. They can thus be measured and costs aggregated to act as a baseline for improvement targets (Sommerville *et al,* 2004). The actual cost of rework and defects is seldom measured by contractors so they have no reliable basis for accurate analysis (Love, 2002).

Josephson *et al,* (2002) discussing the work of Feigenbaum, in a construction context, suggests that costs should be considered on three levels to obtain a holistic view:

- Failure costs; defects that are found either before or after handover.
- Appraisal costs, the costs of checks and inspections.
- Prevention costs, the costs of systems and preventative measures.

The authors do not underestimate the difficulties of implementing measures to capture the costs associated with these elements. Return visits to complete rework and defects are a common factor. They are a very inefficient practice and often lead to multiple cost implications, particularly if the return visits take place during the maintenance period. This often involves extra expenditure on elements such as travelling time, non-productive time, additional access equipment and plant. This phenomenon can be considered in terms of direct costs, specifically associated with the defect and indirect costs, associated with the return visit (Love and Edwards, 2004). The latter authors describe one case where the indirect costs were 22.5 times the direct costs. On similar lines, Nielsen *et al,* (2009), differentiates between 'physical' defects where documentation, material or structure lacks abilities according to contract or good practice. These are contrasted with 'process' defects, where the process takes place in a fashion that represents a significant time or resource loss compared to the optimum.

A small number of field studies are available providing empirical evidence of costs, usually presented as a percentage of TPC. Most urge caution in terms of generalisation and suggest consideration of the particular context is essential. Love *et al,* (2004) notes that a range of rework costs ranging from 3% to 23% are reported in the literature, but cautions that much of the data is estimated due to lack of factual cost reporting. Love *et al* (1999) had suggested that holistic costs of rework could range as high as 12.4% of TPC. Love and Li (2000) carried out two detailed case studies and reported that rework costs in those were 3.15% and 2.4%, also suggesting that use of a formal quality management system can substantially reduce costs of rework and defects. Love and Sohal, (2003) reported that the Singapore Development Board suggested that between 5%-10% of TPC was being wasted on defects and rework costs. Nielsen *et al,* (2009) discussing Denmark, anecdotally report that defects are considered to represent an economic loss of around 10% of construction turnover.

In their longitudinal study, Josephson and Hammerland, (1999) suggested that rework costs ranged from 2% - 6% during construction and additionally 3% - 5% during the maintenance period. Josephson *et al,* (2002) looked at construction related rework (excluding that related to design), finding costs came to 4.4% of TPC, the additional time required to rectify the defects was however 7.1% of time. The authors suggest that on typical projects contractors spend at least three weeks per year, doing rework. American studies indicate a figure of 5% in rework and defects mitigation (Hwang *et al,* 2009). Aoieong *et al,* (2002) reported that nearly 60% of American contractors had not tried to measure rework costs, those that had, returned a figure of around 5% of TPC. In studies in Hong Kong, they also noted that main contractors have no great interest in unearthing the true cost of rework, as the majority of it is carried out by sub-contractors. To some extent the main contractors are only concerned by the end product and not the process that delivers it. As they were not directly suffering any financial loss, they were unconcerned.

Love, (2002[b]) suggests that many costs are hidden in the process and could well range up to 25% in some cases. Noting the lack of any uniformity of suggested cost models, he suggests that field reports should not be taken as definitive, but viewed only as an illustrative source of reference.

Collaboration in the supply chain

The production model in Ireland is generally one of “shell” main contractors, arranging the work of numerous and fragmented sub-contractors, selected on the basis of lowest cost (Green and May, 2005). This structure tends to inhibit the levels of collaboration needed to address problems such as defects (Seymour *et al,* 1997). The Irish industry is at once very adversarial, whilst also having a sophisticated understanding of the possibilities and benefits from collaborative working practices. A substantial majority in the industry feel that collaboration, or at least, better cooperation is an essential element of their future success (Taggart *et al,* 2012).

Karim *et al*, (2006) noted that sub-contractors viewed the main contractor as their 'customer' and showed little concern for other sub-contractors with whom they had to interact or indeed the ultimate project customer. The result of this lack of integration with other sub-contractors is that defects and unfinished work often gets left behind, until they appear on snag lists. Problems as described, are often generated in one part of the process, but not detected until some later stage, tending to multiply the impact of the problem (Koskela *et al*, 2006). A supply chain collaboration approach to the defects drives an agenda of stopping and fixing the problems as early in the process as possible (Liker, 2004). This necessitates management of a process that supports earlier detection of defects and dissemination of information and an integrated approach to problem solving. This suggests a greater role for collaboration and planning between participants. Improvement can be achieved, but requires better ways of measuring and capturing data, from which improvement metrics can be determined (Lee and Amaral, 2002). Tools selected to address the issue must strike a balance between the resources expended upon inspection and prevention of the defects and the consequential cost savings from fewer defects (Nielsen *et al*, (2009). In the context of the Irish industry and particularly the limited resources of the SME sector, they must be seen both to improve the process, by reducing snags whilst also reducing costs holistically.

The emergence of affordable information technology (I.T.) at site level offers potential for significant improvements in supply chain collaboration. The construction industry still relies heavily on traditional approaches, such as paper and pen surveys of defects information. This approach creates bottlenecks in information dissemination and the data is often out of date soon after being issued (Craig and Sommerville, 2007). The latter authors describe the use of one patented snagging management system that was also reported in field trials with major UK contractors (Comit, 2007). The reviews are generally very favourable and cite analysis of cost and time savings, but purchase / set up costs of circa £4,000+ and additional annual running costs of £6,000+ may potentially deter use by SME companies.

The cost of mobile devices has reduced significantly making them easily accessible to the SME market. A low cost, effective software solution for defects management, appropriate to the needs of the SME market is needed to allow collaborative and real-time management of the production process for defects.

Pilot case study overview

As part of wider PhD research, a pilot field study using an AR strategy was undertaken. The first element was to gather knowledge and understanding about practices and attitudes concerning the management of defects and rework in the subject company. AR adopts an inductive approach based on a research cycle, which has as its first step, identification and scoping of a problem (Susman and Evered, 1978). The results presented herein are principally related to the first or 'diagnosing' phase. The problem for the SME was the time and costs involved in on-going rectification of snagging works in a very demanding economy. The problem has a detrimental impact, on their profitability and cash flow.

The project was a health department building. The contract was traditional in nature with design provided by the client. The contractor was selected following a two-stage process. They pre-qualified to the tender list following submittal of extensive information regarding the company and its relevant experience. Tenderers subsequently bid against each other, based on the design provided. The lowest priced tender was selected. Project value was circa €1.4 million. Participants reported that it was generally held as being a 'successful' project.

Study Limitations

The results presented are limited to the diagnosing stage of the AR cycle. This involved the field researcher attending site during the latter part of the construction phase and covers the period just after practical completion. The reporting here does not consider defects manifesting during the defects liability period. Such defects are important and costly to the SME and will be addressed in later reporting of the AR cycle.

Results

Anatomy of a snag

A considerable concern in the construction management literature is the lack of systematic root cause analysis of supply chain problems (Fellows, 2012). This lack of understanding and learning is a contributory factor to the repetitive nature of snags, whereby the same defects tend to be repeated in multiple projects (Lopez *et al*, 2010; Rotimi *et al,* 2011). One of the objectives for this AR cycle thus sought to establish the potential for collaborative effort by the supply chain participants on the project, towards investigation of root causes of the defects found, with a view to their elimination on future projects.

The site managers terminal snag list was analysed. This was the first of several terminal snag lists prepared on the project. It is common in the industry for main contractors to 'pre-snag' the works in this way, prior to inspections by the designers. This action in itself is somewhat of a duplication of effort, time and cost, but is seen as a prudent measure by most contractors.

The manager's list contained 157 separate items. A summary analysis is provided in table 1. In terms of the cost of rework on the project, discussions took place with the contractors' quantity surveyor (CQS). He confirmed that they did not know the actual costs of defects and rework on the project. The CQS said his company did not measure such costs but typically they allowed 1% – 1.25% for snagging in their tenders and he found that was usually satisfactory. It transpired in the discussion that this figure was provided to cover the main-contractors management costs for the snagging process (costs of quality), not for rectification of any actual snags. The CQS stated he did not know what snagging provision costs the sub-contractors allowed in their prices, but he agreed they would indeed provide for them. He did however agree that a substantial 'cost to client / customer' would accrue if all cost streams were aggregated.

To better understand and make visible the costs of snagging, the researcher and CQS priced the site manager's list using daywork rates (typically €23.00 per hour for general trades and €30.00 per hour for specialists). A site inspection was used to allocate estimated hours to the snags listed. Plant and materials estimates and cost were similarly deduced. The agreed estimate for the work on the site manager's list was equal to circa 1.3% of the TPC. It is accepted that this approach is 'ballpark' in nature and simplistic. It was however intended to provide illustrative rather than conclusive evidence. Additionally the costs of the architect, electrical engineers, mechanical engineer and client snag lists must be added. Furthermore costs from additional defects lists, prepared after the elapse of the defects maintenance period may be considered. In this case the defects maintenance period is 12 months. The CQS accepted that in aggregate, 5% or more of TPC (circa €65,000+) could well be spent on defects and snagging rework and snagging process management on this otherwise ‘successful’ project.

Table 2 categorises the 157 snags found on the site manager’s list in terms of broad underlying causes. Factors included poor workmanship such as crooked radiator pipes and work which was damaged after being completed. Other factors concerned work that was only partially completed, such as missing pipework insulation and elements of work that were missing altogether, such as mirrors in the toilet cubicles. A number of snags were directly related to poor design and often needed additional design input / specification to rectify them. This included specification of additional mastic pointing to mask unsightly joints between different materials in various locations. Defects however often have deeper and multiple root causes.

To investigate and highlight the potential for root cause analysis of defects by the supply chain participants, a selection of snags from the manager’s list were identified and subjected to consideration in terms of causation. Six of the listed snags concerned defects associated with co-located electrical sockets. A subsequent walk around with the site manager, noted that there were 15 locations on the site with co-located electrical sockets. Thus 40% of co-located electrical sockets on site were noted on the snag list as requiring some form of rework. Although they are relatively minor defects, most could not be rectified in one visit alone and required several visits, for example, for filling, preparation and painting.

Initial discussions with the manager and the site trades people involved found them in agreement that these types of snags were fairly ‘normal’ they had all seen them many times before. There was an acceptance that they were simply part of the job, another part of the process. This routine acceptance of defects is noted by Sommerville *et al,* (2004) and others. In an Irish context the recent boom saw publication of *'The Irish homebuyers guide to snagging'* a consumer guide for the industries disaffected customers, so that they could better manage the inevitable long list of defects associated with their new homes. That such a book exists, clearly illustrates the entrenched nature of the problem and reflects negatively on the industry.

A site assessment of the co-located socket snags was conducted by the field researcher. This found that of the 15 co-located sockets those that were close together (0-50 mm) tended to have snags, whilst those further apart (>50 mm) had no snags. It was also found that all of the co-located sockets had different spacing distances and appeared to be randomly spaced. By way of a double check a second small project, recently completed by the SME, was inspected and 11 co-located sockets were found. Again the spacing appeared to be totally random. These observations were discussed at a workshop meeting with the contracts director, site manager, and electrical and decorating sub-contractors with photographs available (provided by the field researcher), and yielded the following insights;

- Regarding the random spacing, the group found that the electrical design drawings used CAD symbols to illustrate the approximate location of the sockets. No dimensional layout was usually given. The various electricians executing the work thus randomly decided themselves on what spacing to use.

- Follow on trades were then presented with difficulty due to the (usually) small distance between the sockets. This is not linked to the individual materials used and was found to be common with plaster, plasterboard, paint or tile for example. The issue was the difficulty for operatives, in handing and tooling small slithers of the materials. Larger pieces are easier to handle cleanly and would yield less or no snags.

- The organisation responsible for final rectification of the snags here, mainly the decorators, is typically one of the finishing trades. However the root cause of the snags occurred earlier in the supply chain with the design and electrical installation work. These stakeholders however escape without consequences. The snags are thus often passed off and classified as 'poor workmanship' but is strongly influenced by the lack of explicit design at root cause.

The participants proposed solution to this snag is relatively simple. As the defect is related to the space between the sockets, simply make that spacing larger and remove the random element. The participants suggested that a standard spacing of 100 mm be adopted. A walk around site confirmed there were no dimensional issues preventing such a spacing being adopted. Further discussion suggested that manufacturers (of plastic or metal electrical conduit) could simply supply pre-made and pre-threaded spacers of 100 mm to obviate this problem entirely. In effect, adoption of a 'lean' approach is suggested. This part of the process is to be standardised and if pre-manufactured components were used consistent spacing would be achieved (Koskela *et al*, 2006). There would also be some other potential, modest cost savings in the original work as cutting and threading of conduit on site would be avoided by the electrician. The solution also provides for a more consistent and aesthetically pleasing end product.

Dissemination of this information to the workforce will be achieved by simple and visual A4 instruction sheets. Drafts of such sheets were prepared for consideration and will be further developed and tested as part of future phases of the AR Cycle with the SME.

The example presented above, suggests that the supply chain certainly has the technical knowledge and experience to determine root causes of common defects and to contribute towards viable, cost effective solutions to prevent their reoccurrence. Other defects from the list were subjected to similar scrutiny, yielding potentially promising results.

Results

Overview of management systems

The second area of interest in the problem scoping or 'diagnosing' part of the AR cycle, involved an evaluation of the management systems and processes used to manage the defects and snagging process. The field researcher was generally given free access to all site records and other design information and discussed this data freely with many of the key participants, both informally on the site and formally in interviews. During the course of the production phase of the project the researcher visited site regularly, on a weekly basis. This helped to break down interpersonal barriers with the workforce who became progressively more engaging in discussing the work openly, as time went on.

During the project both the site management team and the design team carried out ad-hoc walk around 'quality' inspections, usually on the site meeting day (fortnightly). These were informal in nature and did not follow any structured format, but did identify a number of defects that were rectified prior to hand over. The sub-contractors on the site did not formally inspect and sign off their own work, but rather left that job to the site manager and design team to do in terminal snag lists. The manager's list reflected many defective snags, but also a number of unfinished items, which were not in themselves defective. However these items needed to be completed, prior to final inspection. Unfinished work also carries a contingent risk of further defects being created during return visits to complete such items.

Often the sub-contractors would start, but not fully complete work because of co-ordination issues with other trades or information deficits for example. They left site or moved onto other work on the site, whilst awaiting return visits to fully complete that activity. This common facet of construction was identified as a type of waste called 'making do' (Koskela, 2004), and its impacts are well described in Emmitt *et al,* (2012) who suggested that this approach is a contributor to higher levels of snags and defects.

On this project there were four snag lists prepared towards the end of the project and one afterwards. Lists were supplied by: (1) the site manager; (2) electrical engineer; (3) mechanical engineer; and (4) the architect. Additionally after handover the client supplied a small list of snags they noted during early occupancy. The basic process of each involved a walk around inspection, at which time snag details were recorded with pen and paper. Upon returning to the office, the details were transcribed to a computer. Regarding the first list, the site manager issued copies by email to the sub-contractors for action. No copy was given to the design team as contractually, the site manager, did not view it a design team matter. The data was supplied as a simple list using Microsoft Excel. The services engineers' lists were similarly compiled and sent to both the main contractor and the specialist electrical and mechanical contractors. Any items of a general nature (not for the specialists) were referred to the main contractor, rather than any named sub-contractor. One list was supplied in Microsoft

Word, the other used PDF format. The architect's list was similarly compiled and sent solely to the main contractor for action. PDF was their chosen format.

Upon receipt of the designer's lists, the site manager had to modify and adapt the lists and decide which sub-contractor was responsible for each item listed, then issue them for sub-contractor action. At an appropriate stage, the site manager, decided that the snagging process was completed and re-inspected his list and signalled the designer's to re-inspect theirs. Shammas-Toma *et al*, (1996) noted severe weaknesses in the 'inspection list' approach to defects detection, as described herein. They report finding many items that had been 'checked off', were in fact defective in some way (albeit, many in a minor way). Additionally they found many additional defects that had not been detected at all. Patton, (2013) agrees that many defects (including failure to meet specifications) are simply never detected, leading to a permanent and significant loss of customer value. He terms this phenomenon, task diminishment.

The four snag list approaches adopted here, were compared to best practice, suggested by, Sommerville *et al,* (2004), to assess the completeness and robustness of the data provided in the lists. See Table 3 below. These results and additional observational assessment on site yielded the following insights emanating from discussions with project participants;

- The lists are idiosyncratic. For example, the two engineers worked for the same design consultancy, yet their lists are not consistent with each other, let alone the other parties. Participants felt that this approach was normal on the projects they had worked on and mirrored their previous experiences. This process is open to inconsistent operation, duplication of effort and communication failures due to lack of any standardised (but flexible) approach.

- Several items listed are general in scope and do not well serve the process. The Architects list for instance has a catch all item of "Touch up all scuffs on walls, ceiling, access panels, woodwork etc." This is unquantifiable and contains no specific locations. It is also open to narrow or wide interpretation by recipients. The implication here is that imprecise communication / language will lead directly to misunderstanding and delay in execution of the works required.

- Several items listed are simply unfinished or missing, rather than necessarily being defective. They need to be completed before they can be properly inspected. Unfinished or missing items can be in that state for many possible reasons. Examples from this project included: (1) 'Making do' as previously described; (2) Operative carelessness; (3) Delivery delay / lack of materials / late instruction; (4) Poor scheduling / trades co-ordination; (5) Design / specification issues.

- Some snags involved collaboration by more than one sub-contractor to achieve rectification. This was not clearly reflected in the snag lists. Thus the responsible sub-contractor may attend and find they cannot remediate the work alone. An example snag involved remedial work to a timber pipe boxing. This was allocated to the carpenter, who rectified it. However following rectification works it then needed to be redecorated, this aspect was not communicated (to the decorator) on the snag list and thus the latter work was ignored.

- The electrical snag list contains a clause indicating that no re-inspection will take place unless the contractor confirms work is completed by signature beforehand. The engineer stated that he had, in the past, been called back many times to find many defects on his lists still outstanding or only partially addressed. The participants generally agreed that this was also a common occurrence in their experience. Many stated that snag list work tended to be an iterative process with several cycles of inspection and follow up rework activity. This has implications in regard to 'costs of quality' since repeat inspection cycles increase costs. Repeat contractor visits to attend to rework are also disproportionately expensive as previously discussed.

- The four lists were disseminated using three different software programmes and using inconsistent styles. This meant the contractor had to manipulate the lists into new documents that could be sent to sub-contractors. Similar issues also prevent viable post contract analysis and reporting from the lists. None of the participants proffered any particular reasons why this was the case, they all stated they would have no objection if a consistent approach was agreed and adopted from the outset. The issue appears to stem simply from a lack of coordination. Such coordination would of course improve communication and the data handling processes.

- The lack of simple data elements such as individual snag numbers and snag completion dates makes it difficult to track completed work and also makes post contract analysis difficult without data re-entry. Again the participants offered no real explanation of why this was the case, other than the disengaged and idiosyncratic nature of the management process being use. Participants clearly understood the logic of allowing better tracking of the project data and also post project analysis for learning purposes and generally were supporting of adopting a more structured approach. They were simply never asked to do so.

- At any given stage of the process there is little real time information on progress. A full re-inspection is required to ascertain any current status position. Participants noted real frustration in the lack of any real time indication of 'where they were' with the snagging process (both here and in their experience). This was particularly evident whereby sub-contractors needed to prove work were complete to release payments (valuations / retentions).

- The client was not consulted on the snagging process and unilaterally added their own small, post-contract list of snags, requiring additional return visits. Participants reported mixed experiences. On some projects clients were heavily involved in the day-to-day workings of projects, whilst others take a 'hands off' approach, having little involvement. No particular consensus was agreed by participants in terms of how the client should be involved in the snagging process.

The results of this overall assessment were discussed with the participants who confirmed that this snagging management process was 'fairly typical' in their experience and that the structure and content of the snag lists were also typical. They generally agreed that a more coordinated and collaborative supply chain effort could have a significant impact in streamlining and improving this area of process management. All noted however that there was no formal forum to address such matters in the current project process used in this project (or on their other projects). All efforts to mitigate defects and rework were unstructured and informal.

All parties agreed that normal practice was to carry out the snagging process individually. Nobody had any experience of any coordinated efforts to eliminate or better manage snagging. It was evident that no shared or collaborative IT systems were used on this project. The Architect noted that he had some experience of such systems from one previous project. The remainder of the parties had no experience of working with collaborative IT.

Suggested avenues for future research

This paper focuses primarily on the first or diagnosing stage of the AR cycle with the SME Company. Some preliminary observations towards measures for the second or action planning stage are also made. Future reports will describe the results of the concluding steps in the AR cycle, where an agreed improvement plan is put into action and then evaluated to study its impact on the problem. Further iterations of the cycle may then be required, to improve the original plan.

Conclusions

This research has considered information gained from the first phase of an AR research cycle with an SME main contractor. Like others construction companies they have suffered in the Irish economic downturn and face very significant financial and resource pressures. The data presented diagnoses problems within their productive processes for the management of defects and snagging. These results allow for some preliminary conclusions to be drawn in terms of improvement potential in these processes. A root cause analysis of a common defect was presented, one of several such defects investigated on the pilot project. The results indicate that the supply chain participants, when adopting more collaborative and pro-active approaches, can identify root causes and suggest possible cost effective solutions to avoid future recurrence. Literature examined from around the world, indicates that defects aggregate to substantial wasted costs and that even modest improvement would yield significant and worthwhile savings throughout the supply chain. The Irish economic situation suggests that the industry will take many years to recover. It is thus likely that any significant improvement in the fortunes of the SME must come via improved productivity and efficiency. Inefficiency can no longer be masked by boom time conditions. The current production process used by the SME to manage defects and snagging does not however provide any forum for, or seek the input of their supply chain towards collaboration into such matters.

The shortcomings in the management system used to collect snagging data and the subsequent process to rectify the defects used by the SME are clearly evident and have been fully exposed herein. Addressing these shortcomings provides a suitable starting point for future process improvement in terms of stage two of the action research cycle (action planning), namely: (1) the adoption of a collaborative supply chain approach; (2) the adoption of a standardised management process to manage defects and rework; (3) the adoption of cost effective IT solutions appropriate for SMEs; (4) the adoption of a simple / basic cost modelling method; and, (5) a focus on learning and continuous improvement. The perilous financial position of the Irish industry is noted. Thus all initiatives to reduce defects (and thus also costs) must be rigorously balanced against any added inspection or process management costs. Collaborative supply chain approaches offer the potential to reduce defects, without adding significant costs to the process, allowing a positive cost result overall.

The results also support the conclusion that participants in the Irish industry profess a desire for more collaborative ways of working. They also have a sophisticated understanding of the potential benefits that such an approach could yield. Sadly they do not, as yet, adopt processes and procedures to match their ambitions for the industry.

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Table 1 Summary Analysis of Site Managers Snag list.

Identified trade	Number of Snags	Est. Hours / cost €		Est. Plant & Mat cost €
Painter	41	60.5	1,573.00	403.00
Electrician	25	60.5	1,815.00	61.00
Carpenter	17	17	391.00	72.00
Furniture	6	6	180.00	0
Mechanical	31	51	1,530.00	125.00
False Ceiling	2	2	60.00	0
Cleaners	1	6	138.00	0
Fencing	1	32	736.00	0
Floor / wall Resin Co.	8	7	210.00	32.00
Not Stated	4	6.5	149.50	233.00
Main Contractor	2	2	46.00	0
Flooring	1	0.5	15.00	10.00
Kitchen Co	2	3.5	105.00	0
Ground-worker	10	59	1,357.00	100
Tarmac	1	64	1,920.00	0
Road Marking	1	6	180.00	0
Landscaper	1	32	736.00	0
Roof / Guttering	1	8	240.00	0
External Door Co.	2	2	60.00	0
TOTAL	157	425.5	11,441.50	1036

(Estimated cost € 12,477.50 (daywork rates applied €23.00 p/h general trades, €30.00 p/h specialist trades)

Table 2 Classification of Site Managers Snag List

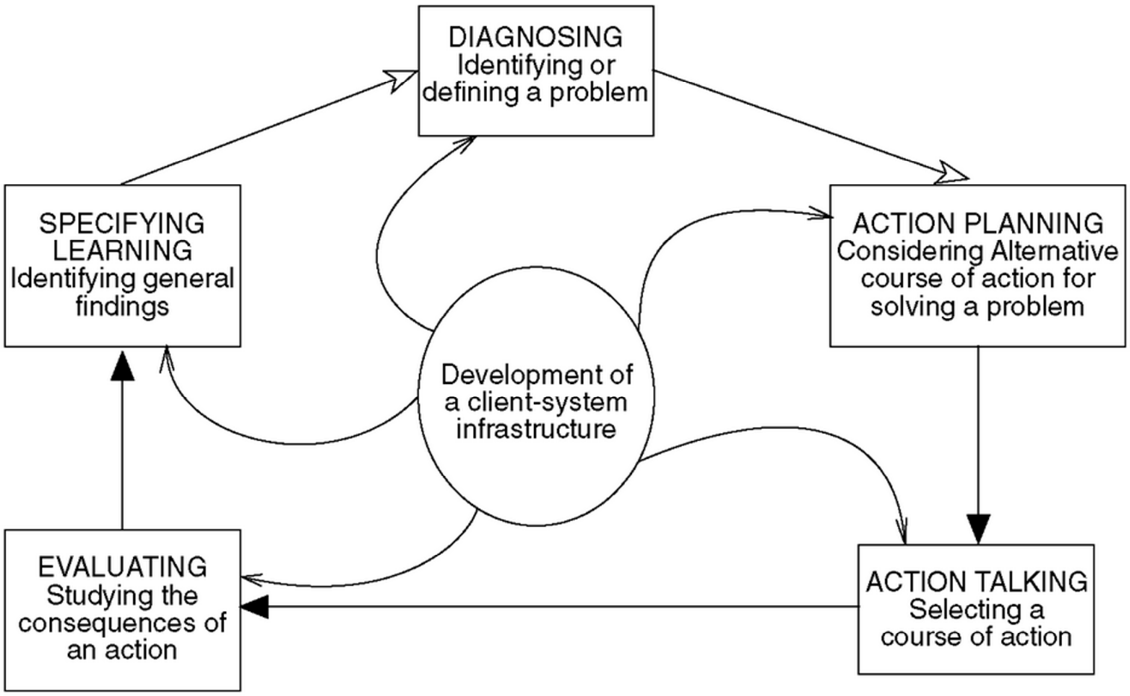
Item defective / workmanship	25
Item defective / damaged following completion	12
Item is not fully completed	46
Item requires additional follow on work	1
Item is missing	54
Item is unsatisfactory / design related	17
Item is unsatisfactory / wrong specification	2
Number of snags	157

Table 3 Data content of pilot study snag lists compared to best practice.

Data attribute	Manager	Architect	Electrical Engineer	Mechanical Engineer
Location of site	✓	✓	✓	✓
List revision number				
Item descriptor				
Snag general details	✓	✓	✓	✓
Document reference		✓	✓	✓
Status of snag			✓	Partly
Updated snag status				
Inspector name		✓	✓	✓
Date snag identified		✓		✓
Exact snag location	✓	✓	✓	✓
Additional details	✓	Partly	✓	✓
General comments option		✓		
Individual snag numbering				
Specific checklist number				
Distribution / allocation	✓		✓	✓
Related packages				
Contractor's confirmations				
Snag completion date				
Client confirmation				
Verified complete by contractor		✓	✓	✓
Final inspector verification				

Source: Adapted from Sommerville *et al,* (2004)

Figure 1 The action research cycle



Source: Susman and Evered (1978)