Poor Quality Cost in Construction: Literature Review

Master of Science Thesis in the Master Degree Programme, Design and Construction Project Management

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Table of Contents

List of figures

List of tables

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Behzad Abbasnejad

Summary

In this master thesis, the literature about construction poor quality cost as the major theme of this master thesis in construction are reviewed presented into two separate papers. The first paper- Poor Quality Cost in Construction: A Literature Review- is about summarizing and analyzing the most significant findings of contemporary studies on the topic of poor quality costs in construction. The method in this paper is based on a systematic literature review. It is tried to gather papers published between 1980 and 2013 in peer-review journals. It is tried to identify the predominant researchers in the construction poor quality cost domain and the related research clusters. Basically, determining what is considered as poor quality cost levels is an area of debate in construction. Three major aspects were identified which are inconsistent in reviewed studies, including: aims of studies, definition and methods of data collection. This categorization provides the opportunity for the readers and users to make distinctions between reported findings of previous studies. Then, it is also possible to point out promising future research directions. This review shows that these factors along with some other factors in construction poor quality costs literatures and the different reported results has contributed to blur the boundaries and create confusion about the poor quality costs. Therefore, the users should be well-aware of using them and for what purpose wants to use the reported findings. Indeed what this literature review illustrates is that one must be careful when comparing and referencing the findings of previous studies as they may not be entirely comparable with one another. Moreover, lack of uniformity about these factors literatures indicates that this research area is still far from maturity and needs more attention from researchers and practitioners.

In the second paper – Poor quality cost in Building Information Modeling (BIM) and Lean Construction (LC) literature: A review of evidences - in addition to reviewing papers about construction poor quality cost, fifty (50) literatures about BIM and LC from seven databases are also reviewed. Implementing both BIM and LC aims directly to influence the level of poor quality cost in construction projects. In other words, one of the common objects of both BIM and LC is to reduce poor quality activities such as rework and hence decrease the amount of cost spent to rectify these types of poor quality related activities. However, their full effectiveness is not yet proved. Many organizations, managers and investors have taken a “wait-and-see attitude” about BIM and LC, waiting for evidences to validate declared promises. Therefore, in the second paper, the literature about poor quality cost, BIM and LC are reviewed to provide guidance for both construction academia and managers on how poor quality cost are used in BIM and LC literature. The results indicate that there is a lack of attention from researchers to follow up the promises in favor of BIM and LC in regards to poor quality cost reduction.

Introduction

In the construction, due to the characteristics of this industry and several other factors, cost of poor quality has emerged to be a key issue. Poor quality breeds several undesirable effects throughout the entire construction project supply chain. When poor quality activities made during the construction processes and are discovered, necessitating costly rework and if undetected, may lead to geotechnical and/or structural failures which can have terrible consequences including delay, cost overruns, severe injuries and even fatalities. In addition, poor quality issues can negatively influence the profitability, performance and reputation of involved organizations and ruins their social outlook.

Hence, construction managers and practitioners have attempted to tackle this issue by adapting concepts from other engineering disciplines. So, approaches ranging from Total Quality Management (TQM) to Building Information Modeling (BIM) and Lean Construction (LC) have been considered as the alternative ways to reduce their impacts on construction projects.

Build on TQM concepts, there are numerous attempts in construction related literature to capture and measure the cost of poor quality. Different investigations reported different findings. But, there is no comprehensive review of previous studies, which describes, summarizes, evaluates and clarifies their findings. Therefore, one of the primary aims of this master thesis is to review the findings of the previous studies concerning poor quality cost in construction.

In addition, poor quality is one of the common concerns of both BIM and LC. Different promises may be found in favor of implementing BIM and LC to reduce cost of poor quality in construction projects. However, there is not a comprehensive review of the evidences for following up these promises.

Therefore, this master thesis is structured in two separate papers. In the first paper, the author presents a review of the published literature about poor quality cost in construction. In the second paper, in addition to the literature about construction poor quality cost, relevant literature about both BIM and LC are also reviewed to develop an overview of how poor quality cost is used in BIM and LC literature.

To sum up the current state of the researches on the related topics especially the topic of poor quality cost in construction, it was started by means of a search for papers in seven databases using relevant keywords to the topics, and then sorting the obtained papers into different categories in order to address the followings:

- the main researchers working in this field
- major findings
- significant gaps and differences among the reviewed literature

Paper 1:

Poor Quality Cost in Construction:

A Literature Review

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1 Abstract

Over the last three decades, a number of studies on the topic of poor quality cost in construction have published in the form of peer-review journals and conferences, but comprehensive overviews of this body of research are not available. For the detailed review of construction poor quality cost research presented in this paper, it is tried to gather papers published between 1980 and 2013 in peer-review journals, though in some cases some other research publications are supplementary used. The emphasis put on the identification of the predominant investigations about construction poor quality cost domain and the related research clusters. The papers are classified according to major aspects, which cause in reporting different outcomes and create confusion. This categorization provides a better understanding in regards to the differences about the aspects considered by previous researches on construction poor quality costs and to analyze them in a more meaningful way and point out promising future research directions. This extensive literature review illustrates that there are several factors, which contribute to the different findings in previous studies. Of that reasons, one should be careful when using and referencing the reported findings from previous studies.

Key words: Poor quality Cost, Quality Cost, Rework Cost, Failure cost, Construction Industry

2 Introduction

The construction industry is mainly project based and a range of complexities are inherent in the construction projects. Quality management principles and tools are critical requirements in construction management practice to accommodate adequately the variability in production, relative to the diverse interests of multiple stakeholders involved in construction projects, and lack of it may result in frequent changes, errors and omissions (Love et al., 1999a). Hence, the lack of quality focus throughout the construction supply-chain may result in poor quality activities, which is considered as non-value adding activities (Josephson et al., 2002) and leads to time and cost overruns in projects. As a result, poor quality can negatively affect the performance and productivity aspects of construction projects (Alwi et al., 2002; Josephson et al. 2002).

However, the implementation of Total Quality Management (TQM) which is defined as "a set of concepts which can be extended to the whole organization, which permits producing products and/or services which satisfy customer demands at the lowest cost possible, and trying to make all the staff within the company feel satisfied with their work" (Amat 1992 cited in Selles et al., 2008) has been employed by many construction organizations as an initiative to solve their quality problems (Kanji and Wong, 1998). TQM philosophy throughout all projects can help an organization to improve its productivity, performance, and both customer and employee satisfactions by eliminating and/or reducing poor quality (Construction Industry Institute, 1989). In order to achieve this goal, it is essential to diminish costs related to not doing things correctly the first time. And this is only possible if these costs are identified and evaluated or put in other words, if quality costs are measured and analyzed (Selles et al., 2008; Love, 2002a).

Measuring and analyzing the cost of quality provide the opportunity to remove and overcome factors cause poor quality (Low and Yeo, 1998) hence provides the potential for significant improvements in terms of productivity and performance. Therefore, it should be considered as an important issue for managers (Schiffauerova and Thomson, 2006). If companies fail to quantify their quality costs, they cannot indicate the cost effectiveness of their quality systems (Love and Sohal, 2003). According to Love et al. (1999b), the cost of quality is one type of measurement, which can provide the user with information about failures in order to learn from the past project to improve the future projects.

Several researchers have been investigated the poor quality costs in construction and civil engineering projects. Even if such poor quality costs are intensely investigated and quantified in the current literature, the differences among them are seldom considered. Different understandings and different information circulate in the debate concerning what is the poor quality cost for construction projects. Sometimes, there is a great confusion, even among researchers about cost of poor quality in construction. The reported findings of the previous investigations are often compared and contrasted to others (see e.g. Oyewobi et al., 2011) without any attention that they may not be comparable. Several factors affect such large confusion in comparing and interpreting reported results. For instance, there is a lack of uniformity in the way in which data have been collected because of the various interpretations as what constitute poor quality (Love, 2002b). Difficulties in gathering poor quality cost stem not only from lack of agreement on data collection methods but also from different considerations of scopes, definitions, proposed terms and some other factors in the literature.

In fact, the explanation for the confusion is that information comes from the investigations in which the definitions, perspectives, scopes and methods are different, sometimes in significant ways. The concepts also cause confusion, as studies of defects, deviations, non-conformance and deficiencies in quality are compared as though these concepts were in some cases synonymous. Despite the many warnings against making comparisons, there is no escaping the desire for data for comparison purposes, which leads to several misunderstandings. Therefore, it is imperative to summarize and analyze the issues regarding construction poor quality costs in order to create a clearer debate and provide a better understanding of the subject. In this paper by reviewing and analyzing the differences and similarities among the current literature about poor quality cost in construction, the aims are, firstly, to increase the awareness among construction researchers and practitioners about the findings of previous studies and secondly, providing a better understanding of issues regarding this topic. Following the overall objective of the paper, some key questions are identified to be of particular interest:

(1) What various terms are presented in the literature?

(2) How do rework and/or related terms defined?

(3) What methods have been used to conduct the studies?

(4) What is the scope of the studies?

(5) Why do the authors conduct the studies?

The structure of the paper is as follows: in section one, the methodology for this literature review is presented. In section two, theoretical backgrounds and concepts related to poor quality cost are explained. In section three, previous studies on poor quality cost in construction are outlined. In section four, the results of the literature are reviewed and categorized into three major groups which include: aims, definitions and methods of data collection. And finally, discussion and concluding remarks are drawn.

3 Method

This paper is based on a literature review of literature about the subject of construction poor quality cost. To find relevant papers, two methods were used. First, electronic databases were searched following by manual searches of reference lists from selected papers. Initially, internet-based searches were conducted in seven databases including: Scopus, ProQuest Dissertations and Theses, American Society of Civil Engineers (ASCE), Taylor and Francis Online, Emerald Library, Science Direct, Google Scholar for finding related papers between 1980 and 2013. The keywords were consisted of the followings or a combination of them: poor quality, poor quality cost, rework cost, failure cost, defect cost, cost of deviations, construction, civil engineering. Then, the abstracts of the obtained papers were reviewed for being relevant. Accordingly, manual searches were used in the reference lists of retrieved papers to expand the search and find more relevant papers.

Finally, all papers were critically reviewed and analyzed in order to find out the bases for evaluation and comparison. This resulted in finding three major bases, which have the greatest influence in reporting different findings among the studies. These include, but are not limited to the followings:

- Aims of studies
- Definitions and terms
- Methods of data collection

In this review, 200 publications in total are analyzed for the purpose of providing information concerning poor quality cost. Among the searched publications, about 90 peer-reviewed sources discussing poor quality cost and quality cost for construction and the literature about quality cost in general which can supplement the discussion were found.

These publications include relevant papers in peer-review journals, and conferences. Other articles such as exclusive reports in news magazines, newsletters, and editorials are left out as the author feel that they deal with general information in a limited manner. It is tried to have a scientific view, though some relevant reports have been reviewed in order to have a comprehensive insight to the importance of poor quality cost in construction and common challenges and confusions that may exist among the researchers and practitioner. Most of the literatures are construction and civil engineering related, though it is tried to search for articles discussing quality cost and poor quality cost in general to provide a deeper insight into the subject.

4 Theoretical Background

In this section, in order to make a clear understanding of the related subjects and terms, and formulate a foundation for further arguments, an overview of related theoretical backgrounds is presented.

4.1 The concept of quality costs

The economic benefits of quality improvement have long been underlined by quality management experts and researchers (Freiesleben, 2005b). Improving quality through reducing poor quality activities brings several advantages such as: increased productivity (Freiesleben, 2005a; Castelvecchi, 2003) improved morale (Castelvecchi, 2003) and increased adaptability in the process of change. According to Freiesleben (2005b), quality improvements increase the chance of significant profits to be gained by providing better production quality, which translates into higher expected utility for the customer. The quality cost in TQM is one of the most key tools for the improvement of a quality management system (Dahlgaard et al., 1992). Converting the quality problems into financial terms and expressing them in terms of quality cost provides a more meaningful tool for managers to gain knowledge about the level of quality in their organizations (Superville et al., 2003).

The concept of cost of quality is first introduced by Juran as the "Cost of Poor Quality" in his "Quality Control Hand book" in 1951. Subsequently, Feigenbaum (1951) has derived the classification called the Prevention, Appraisal, and Failure (PAF) model. In this model, quality costs are divided into prevention, appraisal and failure costs. Crosby (1979) further redefined the cost of quality as the sum of "Price of Conformance and Price of Non-Conformance". A number of papers published on quality related costs in construction refer to these traditional classifications at least at some level (Davis et al., 1989; Abdul-Rahman, 1993; Low and Yeo, 1998; Love and Li, 2000; Barber et al., 2000; Hall and Tomkins, 2001; Aoieong et al., 2002; Josephson et al., 2002; Kazaz et al., 2005; Rosenfeld, 2009).

Several models have been presented for cost of quality. However, the most significant models can be classified into the following groups (Schiffauerova and Thomson, 2006):

1. Opportunity or intangible cost models: (Prevention costs + Appraisal costs + Failure costs + Opportunity costs) / (Cost of conformance + Cost of non-conformance + Opportunity costs) / (Tangibles + Intangibles):

Intangible costs are costs that can be just estimated. Examples of these include: delays and work stoppage due to defectives and profits not earned due to lost customers as well as reduction in revenue because of non-conformance (Schiffauerova and Thomson, 2006). Any amount of reductions in the tangible external failure costs will directly reflect in the reduction of intangible failure costs (Juran and Gryna, 1988).

2. Process cost models: Cost of conformance + Cost of non-conformance:

In this model, the emphasis is on processes rather than products or services. And process cost is calculated as total cost of conformance and non-conformance for a specific process (Schiffauerova and Thomson, 2006).

3. ABC models: Value added + non-value added:

Exact costs for various cost elements are obtained by identifying resources of costs to eliminate non-value adding activities (Schiffauerova and Thomson, 2006).

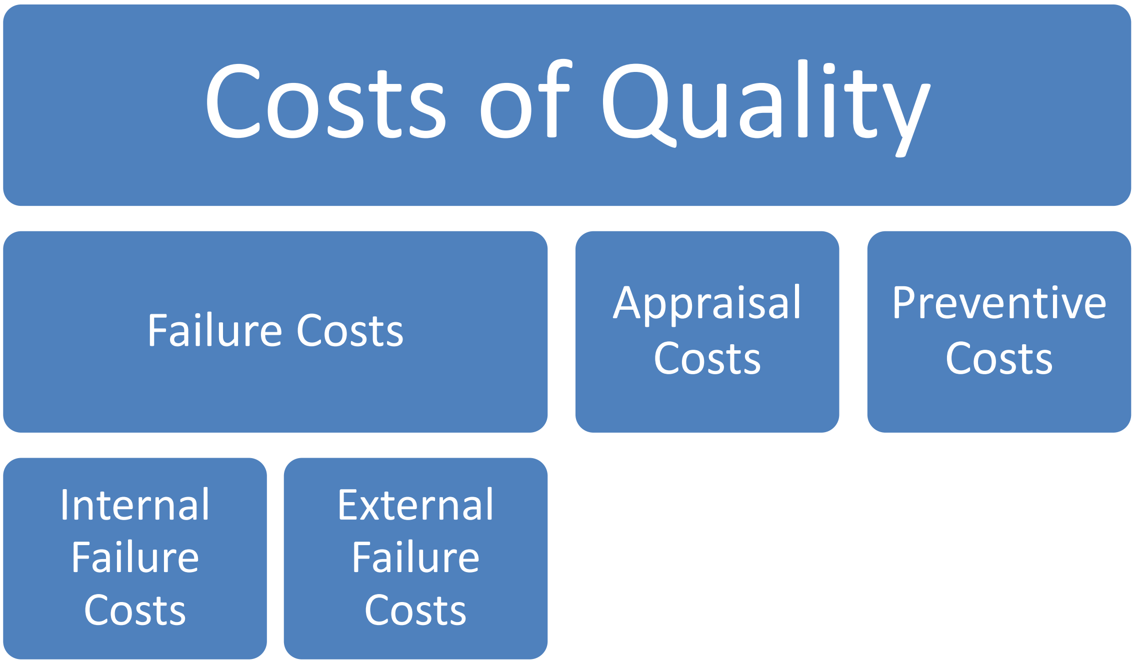
4. Crosby's model: Cost of conformance + Cost of non-conformance:

This model is similar to the P-A-F model (Schiffauerova and Thomson, 2006). Quality here means "conformance to requirements" and the cost of quality is defined as the sum of price of conformance and price of non-conformance (Crosby, 1979).

5. P-A-F models: Prevention costs + Appraisal costs + Failure costs (internal and external) (Fig. 1)**:**

This model is the widely accepted quality cost categorization (Schiffauerova and Thomson, 2006) which is introduced by Feigenbaum (1956).

Figure 1: Cost of Quality according to PAF Categorization



- The cost of poor (or cost of non-conformance) quality includes:
  - Internal and external costs resulting from failing to meet requirements.
- The cost of good (or cost of conformance) quality includes:
  - Costs for investing in the prevention of non-conformance to requirements.

- Costs for appraising a product or service for conformance to requirements.

Cost of Poor Quality: Internal Failure Costs

Internal failure costs are costs that are caused by products or services not conforming to requirements or customer/user needs and are found before delivery of products and services to external customers. Otherwise, they would have led to the customer not being satisfied. Deficiencies are caused both by errors in products and inefficiencies in processes. Examples include the costs for: rework, delays, re-designing, disposal of defective products, shortages, failure, analysis, re-testing, downgrading, downtime due to quality problems, lack of flexibility and adaptability and net cost of scrap.

Cost of Poor Quality: External Failure Costs

External failure costs are costs that are caused by deficiencies found after delivery of products and services to external customers, which lead to customer dissatisfaction. Examples include the costs for: complaints, repairing goods and redoing services, warranties, customers' bad will, losses due to sales reductions and environmental costs.

Cost of Good Quality: Prevention Costs

Prevention costs are costs of all activities that are designed to prevent poor quality from arising in products or services. Examples include the costs for: quality planning, supplier evaluation, new product review, error proofing, capability evaluations, quality improvement team meetings, quality improvement projects, quality education and training.

Cost of Good Quality: Appraisal Costs

Appraisal costs are costs that occur because of the need to control products and services to ensure a high quality level in all stages, conformance to quality standards and performance requirements. Examples include the costs for: checking and testing purchased goods and services, measurement equipment; process control monitoring; inspection and tests; test equipment expense; product quality audits and field testing.

The total quality costs are then the sum of these costs. They represent the difference between the actual cost of a product or service and the reduced cost given no defective products. An increase in costs on prevention and appraisal leads to a decrease in failure costs (Fig. 2).

By the passage of time, cost of quality was later replaced by the term cost of poor quality (COPQ) (Malmi et al., 2004) which is defined as the sum of those costs that would vanish if there were no quality problems (Juran, 1989).

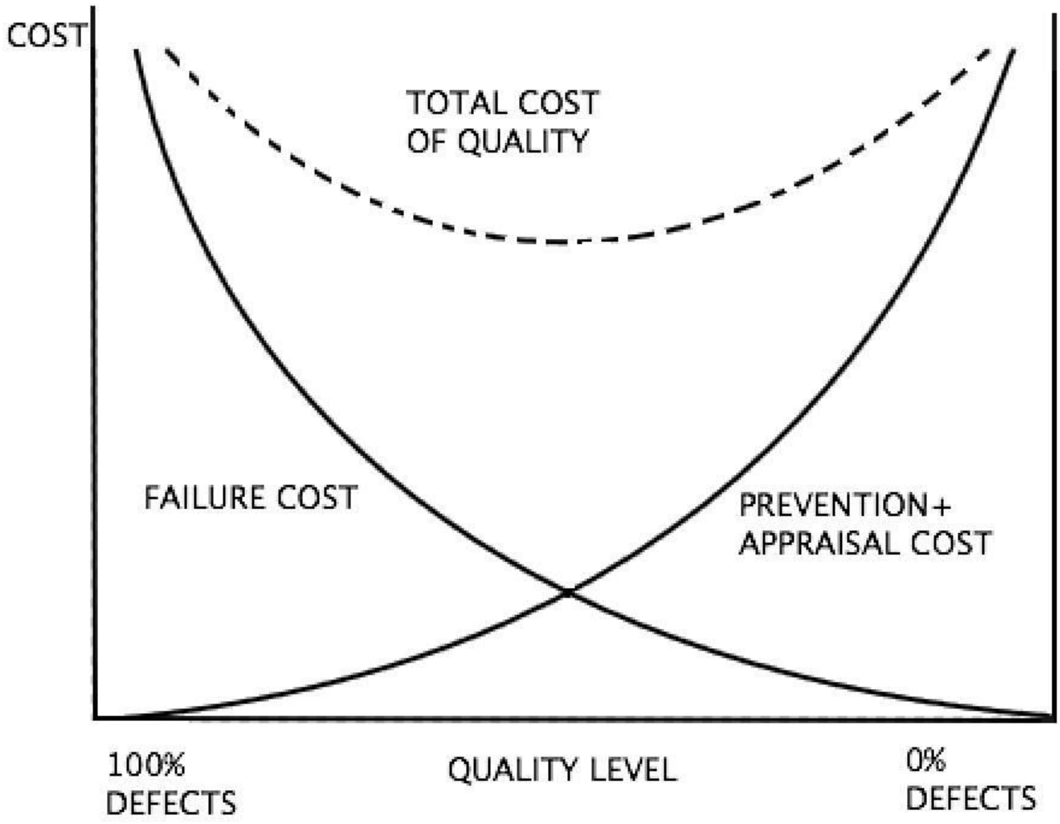


Figure 2: Cost versus Quality Level according to the PAF Model (adapted from Kazaz et al., 2005)

Both internal and external failure costs can be either visible or hidden. Visible failure cost is the cost of errors and their consequences that we have with the current knowledge and methods can capture and record. The causes of poor quality, sometimes, are not as obvious as they might seem (Atkinson, 1999). Many of the poor quality costs are hidden and very difficult to capture and measure. Hidden failure costs are costs for the errors and consequences of faults, which we have neither the knowledge nor the metrics to capture. By developing knowledge and methods more hidden failure cost can be visible. This also increases the opportunities to reduce failure cost. These hidden costs are very important due to the fact that the buying decisions by the customers are very much reliant on these costs of loss of customer good will, lost reputation, customer dissatisfaction and lost opportunities. One of the key elements of the efficiency of the investigations is therefore to highlight so many hidden failure cost as possible (Krishnan, 2006).

4.2 The importance of using and measuring poor quality cost

Some of organizations and managers especially in construction, unfortunately, do not have information about the true cost of their own quality. However, uses of quality cost bring significant benefits. Harrington (1999), for instance, enumerated the uses of knowing quality cost as: (1) getting management attention; (2) changing the way the employee thinks about errors; (3) providing better return on the problem solving efforts; and (4) providing a means to measure the true impact of corrective action and changes made to improve the process.

But, before quality cost can be used, it must be measured. However, the quality cost cannot be captured or identified by means of the current accounting reports and auditing system (Barbará et al., 2008; Low and Yeo, 1998) and it should be captured by means of specific methods and systems. Reviewing current literature illuminates that basically sequential steps in measuring poor quality cost are as follows:

1. Identify all activities that exist only because of poor quality.

2. Identify where in the construction projects the cost of each activity is experienced. These costs may appear in one area or in multiple areas.

3. Determine the method will be used to capture and calculate the cost of poor quality.

4. Collect the data and estimate the costs.

According to Yang (2008), the most important aspects in measuring quality cost are as follows:

- "To establish appropriate categorization of various quality costs, and ensure that every item of quality costs is captured;
- To collect and analyze the relevant data thoroughly, and thus to quantify all quality-cost items accurately;
- To identify areas of poor performance on the basis of the above data analysis; and
- To allocate responsibilities for the overall cost"

In the construction related literature, several researchers (e.g. Davis et al., 1989: Low and Yeo, 1998; Abdul-Rahman, 1993; and Love and Li, 2000) have stressed the importance of measuring the costs of poor quality as a part of quality cost. For instance, Love and Li (2000) made the point that it is essential to identify the costs and causes of construction rework in order to evaluate how quality has been managed and to discover problems within the construction process and try to improve the performance of projects.

5 Overview of Studies on Poor Quality Cost in Construction

In this section, summaries of the most significant studies are outlined to provide a general overview of what have been done in this research area.

Several investigations can be found in the recent literature about poor quality cost for building and construction projects. In the study by Burati and Farrington (1987), a quality performance management system (QPMS) was developed to track the cost of quality. Historical data for nine construction projects of varying type and size were analyzed. 88-1463 deviations recorded per project. Quality deviations found to be as high as 12.4% of the contract value.

Building Research Establishment (BRE) (1982) found that substantial cost benefits can be gained by implementing a quality management system. It is further found that 15% savings on total construction costs could be gained by eliminating rework, and by spending more time and money on prevention.

Hansen (1985) in a study calculated failure cost for three projects; all apartment buildings executed turnkey projects. He studied the available documentation, and supplemented by interviews with staff. For those two chosen projects calculated failure cost calculated to about 11% of the production cost. For the third project, a normal one, the corresponding value was 5.5% of the production. He pointed out that the result of the applied method is likely to be underestimates of the true level.

Ball (1987) reports that a British contracting company managed to reduce total failure cost for a construction project from 4.1% of the tender amount to 0.6% for another project. They studied the faults occurred for the first project and took defect prevention on the basis of the trends to reveal the errors.

From 1986 to 1990 and then 1990 to 1996 Josephson and Hammarlund (Josephson, 1990, 1994; Josephson and Hammarlund, 1996) conducted a numbers of studies to capture the costs and causes of defects. A study performed on seven building project by cooperation of Chalmers University of Technology and a group of construction companies in Sweden during 1994 -1996. Reported costs of defects varied between 2.3% and 9.4% of the contract value of each project. Another 21 site visits were conducted within 3 weeks. The costs of failures reported to be 6% of the production cost.

Hammarlund et al. (1990a, b) in the first investigation during 1986-1989, conducted a study throughout the construction of a community service. Project was followed throughout its course, by an appointed observer over a two-year period and 1460 quality failures recorded on site. Internal failure costs reported about 6 % of production cost. Josephson and Hammarlund (1999) reported the costs of rework on different types of building projects which were varied from 2% to 6% of their contract values.

Josephson et al. (2002) (in their second investigation during 1994-1996) studied seven construction projects managed by seven different companies in Sweden. They recorded 2,879 errors or defects and the costs of rework were 4.4% of the construction values for the observation period.

Cnuddle (1991) measured the failure costs in construction by investigating the amount of non-conformances that happened on-site. Cnuddle (1991) reported non-conformance cost varied between 10% and 20% of the total project cost.

Abdul-Rahman (1993) developed a quality cost matrix to track the cost of non-conformance during construction. To test his model, he reported non-conformance costs during a highway project to be as high as 5% (1995) and during a construction of a water treatment 6% (1996) of the contract value. He gathered 72 non-conformances of which 59 non-conformances were used for analysis in 1995 and 62 non-conformances in 1996 by visiting 18 sites during 22 weeks.

Nylen (1996) found that by implementing poor quality management practices in a railway project, quality failure cost was as high as 10% of the contract value. He further reported that 10% of the experienced quality failures accounted for 90% of their total cost.

Willis and Willis (1996) used a case study to test the quality performance management system (QPMS) system on a heavy industrial project. They reported that the total quality cost of quality (TQC), the cost of prevention and appraisal plus the cost of failure and deviation correction was 12% of total labour expenditures for design and construction. This was consisted of 8.7% prevention and appraisal and 3.3% deviation correction.

Low and Yeo (1998) proposed a construction quality cost quantifying system (CQCQS) for capturing the construction quality costs. Coding system was used in this model to categorize various items. However, this system was not tested further.

Love and Li (2000), in their study of rework costs for a residential and industrial building in Australia, calculated that the cost of rework to be as high as 3.15% and 2.40% of the contract value respectively. Data were gathered from the date construction commenced on site until the completion of defect liability period.

In another study performed by Love (2002b), direct and indirect rework costs from 161 Australian construction projects were obtained. Mean direct and indirect rework costs were reported to be as high as 6.4 and 5.6% of the original contract value, respectively.

Barber et al. (2000) developed a method to capture quality failures costs in two major road projects in UK. For gathering data, two schemes were selected and failure costs calculated based on the weekly budget. Schemes 1 took nine weeks and failure costs originated from 188 incidents reported 16% of the weekly budget. Scheme 2 took just four weeks and failure costs originated from 50 incidents found as high as 23% of weekly budget.

Aoieong et al. (2002) introduced an alternative approach based on the process costs model (PCM) to record and trace quality costs of construction projects. The main purpose of this model was to measure quality costs of particular processes rather than the quality costs of total project (Tang et al., 2004). To test their model, they conducted two case studies including a 38-story building project and one civil engineering project in Hong Kong (Tang et al., 2004). Researchers captured quality costs in concreting process for these two projects. For the 38-building project the costs of non-conformance decreased from 0.48% of the total process costs in the 21st floor (1st cycle) to 0.43% at the end of project in the 38th floor (18 cycle). For the civil engineering project, costs of non-conformance declined from 3.55% (1st cycle) of the total process costs to 0.03% (30th cycle).

Hall and Tomkins (2001) presented a methodology for evaluating the "complete" cost of quality for construction project. Subsequently, the methods were used in a building project in the UK. Quality failure costs reported 5.84% of the contract sum whereas costs of prevention, appraisal and other activities were reported 12.68% of the contract sum.

Kazaz et al. (2005) presented a model for determining the optimal level of total quality cost and collected data for costs of quality in a mass-housing project as a case study in Turkey. The optimum cost of total quality was reported as high as 16.75% of the total cost to client.

Simpeh et al. (2012) reported the mean of direct and indirect costs of rework 2.93% and 2.20% of the contract value respectively by sending 399 questionnaires via email of which a total of 78 firms participated in their investigation.

6 Results

In this section the results of reviewed studies are covered according to the three major bases. The results are also synthesized in Table 1.

6.1 The Aims of Reviewed Studies

One of the important differences among poor quality cost studies in construction is the different aims of them. Numerous and diverse aims could be found in the reviewed studies. However, they might be categorized as the following broad groups:

1. ***Those studies that aims to introduce and develop the methods and systems for capturing and controlling of quality costs:***

Several studies attempted to introduce a system and method for measuring and capturing the costs of poor quality. This theme is the most popular one among the literature about the topic. Examples of those studies that fit this category are:

- Construction Industry Institute (CII) (1989): "To identify methods and programs of quality management currently being utilized in the construction industry".
- Davis et al. (1989): "A quality performance tracking system (QPTS) has been developed to provide for the quantitative analysis of certain quality related aspects of projects by systematically collecting and classifying costs of quality".
- Abdul-Rahman (1993): "Illustrate by a case study how failure costs can be captured and used in a civil engineering contract" which led to the introduction of quality cost matrix.
- Aoieong et al. (2002): "How a simple methodology can be used to capture quality costs in construction projects".
- Low and Yeo (1998): "Proposed a quality cost quantifying system for site operations known as the construction quality costs quantifying system or CQCQS for the building industry".
- Kazaz et al. (2005): "This paper examines construction quality costs in Turkey. A model is presented for determining the optimum level of total quality cost. This uses a case study in which the costs of quality in a mass-housing project were collected and evaluated".
- Hall and Tomkins, (2001): "This paper presents a methodology for assessing the complete COQ for construction projects and reports on the findings of a building project in the UK on which the methodology was piloted".

  "This study by interpreting the COQ methodology in far broader terms attempts to apply the complete methodology to a construction project".

- Barber et al. (2000): “This study aimed to conduct a COQ analysis in Civil engineering developed a method to measure costs of quality failures. (It was based largely upon work-shadowing”.

It is worth mentioning that in some of these studies researchers later on by using case studies tried to collect data to test their models and indicated the applicability of their models (Abdul-Rahman, 1995; Abdul-Rahman et al., 1996; Tang et al., 2004). Example of such studies is the study by Abdul-Rahman (1995) who provides a case study on a highway project to support testing his quality cost matrix model. The main point here is not so much of the accurate estimates, but to help the users of the models and systems to get familiar with how to make use of the quality cost systems. And it might be justify why the numbers of recorded non-conformances in this study are very low in comparison to other studies. There is no doubt that some projects are well-run and successful projects, but few errors do not occur in any project.

2. *Quantifying poor quality cost and identifying their associated causes:*

The second group of literature aims at measuring the poor quality causes and costs. They tried to present rather the accurate size of poor quality costs and the origins of their causes as much as possible. So, they tried to choose definitions and methods of data collection, which help them to collect their related data. In this group of literatures, the main focus of the researchers is on how they can employ better tools and measurement’s methods so provide and present a more precise estimate of poor quality cost.

- Construction Industry Institute (CII) (1989): “To identify quality problems in construction along with their associated costs”.
- Josephson et al. (2002): “To measure the costs of rework in construction projects”.

  “Identify, analyze and discuss the causes, magnitudes and costs of rework experienced in seven Swedish construction projects”.
- Love and Li (2000): “The research presented in this paper quantifies the causes, magnitude and costs of rework experienced in two construction projects that were procured using different contractual arrangements”.
- Barber et al. (2000): “The research objective was to provide some overall quantification of the scale of cost involved for the element of work examined”.

3. *Those who aim to increase the awareness and consciousness about the poor quality cost issues:*

In the third group, the main aim is mentioned as to raise the awareness of the managers and other practitioners about the size and level of poor quality costs in the construction projects. In these studies, the researchers tried to stimulate the debates. They also try to provide some recommendations for improving the situation. They may not even present a concrete definition of the poor quality cost the same as other studies and the way they gathered data. It can be argued that the key role of such studies is to raise awareness and consciousness concerning the size and importance of poor quality costs which can be very helpful in the process of managing change. The examples of some of the aims that fall in this category include:

- Abdul-Rahman (1993): "Generate an awareness of the design and construction caused failures".
- Josephson and Hammarlund (1999): "The purpose of the study presented here is to stimulate improvements by indicating where preventive measures are more effective as well as how to perform them"; and

  "The aim is, through increasing the knowledge of defect causes to find motivation for improvement of the building process".
- Barber et al. (2000): "Raise quality consciousness in the process of managing change".

4. *Those studies that aim at presenting definitions of quality related terminology:*

It was surprising that when looking at the aims of the literature, there was only one paper in which the aim was mentioned to present the definitions of related terms. This includes the following:

- Construction Industry Institute (CII) (1989): "To derive and present standardized definitions of quality related terminology in construction".

6.2 Definitions Related to Poor Quality Cost in Reviewed Studies

A common problem when measuring the cost of poor quality is the disagreement about which costs and costs elements should be regarded as poor quality costs (Sörqvist, 1997). Literatures on poor quality costs in construction have set their theoretical basis on quality management concept. As a result, many of the terms used for referring to poor quality are defined from a quality management perspective.

According to Machowski and Dale (1998), there is no general consensus on a single definition of poor quality cost, which indicates that there are many likely ways for proposing different definitions as well as the interchangeable usage of them. More specifically Loushine et al. (2006) cited in Hoonakker et al. (2010) found that researchers in construction quality used the following definitions for quality performance: 'meeting expectations of the customer' (Chase, 1998; Kanji & Wong, 1998; McKim & Kiani, 1995; Torbica & Stroh, 1999), 'reduced rework or defects' (Atkinson, 1998; Love et al., 1999; McKim & Kiani, 1995; Pheng & Wee, 2001; Sypsomos, 1997), 'repeat business' (Sommerville, 1994; Sypsomos, 1997), ‘conformance to ISO 9000 criteria’ (Bubshait & Al-Atiq, 1999; Sun, 1999), and ‘completion on-time and within budget’ (Courtice & Herrero, 1991; Gransberg et al., 1999; Jaafari, 1996; Kiwus & Williams, 2001; Love et al., 1999; McKim & Kiani, 1995; Ripley, 1996; Sypsomos, 1997; Wong & Fung, 1999).

As a result, poor quality cost can also be interpreted and characterized differently. Noticeably, in construction related literature, poor quality cost is expressed by various terms and interpretations and there is not an agreement about them. Examples of such terms, which are in some cases interchangeably used with each other are: “rework” (Love and Li, 2000) (Josephson et al., 2002) “quality failures” (Barber et al., 2000), “defects” (Josephson and Hammarlund, 1999), “non-conformance” (Abdul-Rahman, 1993) and “quality deviations” (Burati et al. 1992).

However, these terms are not often synonymous. For example, failure is defined as “a departure from good practice, which may or may not be corrected before the building is handed over”, while defect is “a shortfall in performance which manifests itself once the building is operational” (Atkinson, 1987). More specifically, defects are considered as “the physical manifestations of an error or omission” (Knocke, 1992). Mills et al. (2009) defined defects as “tangible incidence that can be corrected”.

Basically when a failure occurs, rework is needed which means that a piece of work may take twice amount of time, labor and material. So, rework may stem from different sources. It might be originated, for example, from inefficient information flow in design (Love et al., 1999a). In other words, rework occurs due to inadequate communication of information such as design intent or specific detailing, and work being allowed to proceed without the required information. As a result, collisions of work elements identified in the field after installation result in rework, such as removal and reinstallation of pipes and conduits, incurring delays and extra costs.

Several researchers (Reason, 1990; Blockley, 1992; Petroski, 1985, cited in Atkinson, 1999) made a distinction between two types of errors, which are “active” and “latent”. Latent errors are considered as managerial failures, which dispose a system to failure and active errors are triggering events, which are the direct origin of the failure such as a simple lapse by an individual operative. According to Shingo (1986), cited in Escalante (1999), defects are the outcome of errors. Humans are prone to commit errors, and it is perhaps impossible to eliminate them completely. Nonetheless, it is possible to prevent them from being transformed into defects (Escalante, 1999). Variation is defined as differences between things, even if produced under presumably the same conditions (Shewhart 1931, cited in Escalante 1999).

Mitra (1993) defines "nonconformity" as a quality characteristic that does not meet its specified requirement. A "nonconforming unit" is one that has one or more nonconformities such that the unit is unable to meet the intended standards and is unable to function as required. Some may argue that the modem term for "defect" is "non-conformity," and a term for "defective" is "nonconforming item." However, Banks (1989) makes a distinction between non-conformity and defect by establishing that nonconforming is related to not meeting specifications and that defect is related to not being useful, instead of not meeting requirements.

Some of the scholars put emphasis on the importance of making the distinction between the proposed terms and definitions and the following effects it breeds for the subsequent measurements. Specifically, Mills et al., (2009) figured out that “the lack of differentiation between the terms used to describe defects can lead to inaccurate and incomplete measurements, cost determination and possibly inappropriate strategies for reducing their occurrence.” Plunkett and Dale (1987) emphasized on providing a rigorous definition when the aim is to deal with costing exercise such as quantifies the quality cost. According to Low and Yeo (1998), it is not efficient to include all quality cost activities into the quality cost studies as all of those activities may not influence the overall cost of quality (Low and Yeo, 1998). Hence, in poor-quality-cost investigations researchers must decide to determine quality-costs related elements so they can identify whether a particular cost is quality-related (Dale and Plunkett, 1987).

Presenting different definitions and terms together with the lack of agreement about the quality related definitions of quality and the broad nature of the definitions of quality resulted in including different categorizations and cost elements in the studies which give rise to the confusions and problems related to definition. For instance, it is possible that a product meet a “specified requirement”, but not “satisfy the customer”. It is probable for something to be “free from defects”, but not be “fit for purpose”. A service may be of “superior performance”, but not “conforming to the specification” (Hardie and Walsh, 1994).

In the construction related investigations about poor quality cost, in one study performed by Burati and Farrington (1987), the term *deviation* was used rather than failure or defect. They did so to illustrate that a product or result that does not fully conform to all specification requirements does not necessarily constitute a failure. They argue that deviation can include products or results that do not conform to all specification requirements, but that are not failures in the sense that they require rework, repair or replacement. In their study, the term deviation is referred to a wide variety of other related terms. For example, they discuss that if a product, process or service did not meet established requirements then it was considered as deviation. Deviation was considered as an imperfection which is an accepted deviation, defect which is always rejected and requires corrective action, or non-conformance that may be rejected, requiring corrective action, or may be accepted.

They also categorized deviations as changes, errors or omissions. Subsequently, a change is defined as “a directed action altering the currently established requirements”. Error was considered as “any items or activity in a system that is performed incorrectly resulting in a deviation” and omission was explained as “any part of a system, including design, construction and fabrication, which has been left out”. However, they do not consider the effect of failure on time-related and also the cost that needs to speed up work to compensate the lost time and the cost of delays related to them in their definitions.

Josephson (1994) used the term *defect* instead of rework and defined it as "the non-fulfillment of intended usage requirements" and subsequently defines the defect cost as "the value of resource consumption for rework as a consequence of a defect". The resources are considered as work time, materials and equipment time. This means that a "defect is a non-desired condition in the product or process", which results in an incorrect action. Josephson (1994) argues that even though the usage requirements are given by regulations, building standards, contract documentation and other project documentation, some of the requirements are difficult, if not impossible, to specify. As a result, in order to distinguish whether a particular requirement is fulfilled, it is necessary to rely on the project participants' report. It is noteworthy that he did not consider "the changes, which are made because of new or changed clients' needs" as defects. Thus, the costs incurred due to the client changes excluded in the defect costs in his study. Furthermore, he limited the definition to the cost needed to correct defects and ignored the defects that are not corrected. However, some may argue that the uncorrected defects may have the consequent cost later.

Barber et al. (2000) use the term *quality failure* as "a subsection for measuring non-conformance costs" (Love and Edwards, 2005) for referring to poor quality conditions and classified it as:

- Internal failures: cost incurred due to scrapping or reworking defective product or compensation for delays in delivery; and
- External failures: cost incurred after the delivery of a product to the customer-costs of repairs, returns, dealing with complaints and compensation.

However, they made no distinction between internal and external failures which discovered by the client.

Moreover, in Barber et al. (2000) "only direct costs of rework for the failures observed were estimated: site overheads and work undertaken for the site from head office have not been included in estimates for rework of quality failures". Also, "an estimated cost of delay was included within the cost of a failure where it was on the critical path". Otherwise, it is excluded from the calculations.

Love and Li (2000) used the term *rework*. Love et al. (1999b) defined rework as "the unnecessary effort of re-doing a process or activity that was incorrectly implemented the first time". This means that the additional cost due to re-doing or re-designing an activity or process was considered as a rework. They considered costs of rework as total costs "derived from problems occurring before and after a product or service is delivered". In the same study, Love et al. (1999b) figure out that "the rework costs were determined by calculating the client initiated variations (additional cost to the client) with variations that were not client initiated and defective work". Love and Edwards (2005) further argue that terms such as errors, omissions, changes including change orders, failure, damage, defects, variations and non-variations throughout the procurement process are all attributes to rework, and the costs of them could be included in rework cost. They also considered repairs as one of the items that contribute to rework and define it as “the process of restoring a non-conforming characteristic to an acceptable condition even though the item may still not conform to the original requirement”. Seemingly, including a wide variety of terms as rework is because of the broader definition that they adopted for their study in comparison with some other studies. Moreover, Love and Li (2000) argue that the loss of time because of waiting and redoing work is a non-productive time; however, they did not consider it in rework cost calculation.

Abdul-Rahman (1993, 1995, and 1996) used the term *non-conformance*. In Abdul-Rahman (1993), failure cost is stated as the price of non-conformance which consists of internal failure, external failure, and intangible quality costs. It is also mentioned that “non-conformance costs include those incurred for rework, repair, loss of client’s goodwill, liquidated damages and litigation” (Abdul-Rahman, 1993) and failure cost is “the cost incurred to rectify a departure, which may be in the form of an imperfection, non-conformance or defect, to meet established requirements” (Abdul-Rahman, 1995). In the first attempt to collect data in (1995), 12 classifications of non-conformance including: “geotechnical, design related, planning, information and communication, materials, construction related, plant and equipment, difficult to work area, personnel, subcontractor and supplier, supervision and inspection and other problems” were presented in a matrix model. Nevertheless, material wastage and head office overheads were excluded from his calculations. For each classification of problems, the following items were declared:

- *Specific problem*
- *Activity affected and when discovered*
- *Causes of problem*
- *Extra duration needed to correct problem*: the extra time needed to remedy the problem i.e. actual duration minus estimated duration.
- *Additional cost of activity*: the additional costs (costs of labor, material and plant) incurred by the activity to rectify the problem using normal rates of production.
- *Amount of additional time-related on cost:* the additional time-related cost incurred because of extra time needed to complete the activity or additional costs required to speed up work as a result of the problem.
- *Any other additional cost:* any other additional remedial costs not associated with the two previous items but adding to the activity cost indirectly.
- *Prevention/appraisal costs for this activity:* the expected cost or cost incurred to prevent the problem.
- *Quality cost:* the total quality cost for the activity.

Hall and Tomkins (2001) by criticizing the previous studies as being partial, instead of measuring only the failure costs, presented a broader picture of quality cost. In their investigation, the prevention and appraisal activities were also considered in addition to the failure activities. Initially, it is stated that “what should be measured is any disruption to the construction of finished product, however that may manifest” which seems that only the visible costs were considered. Further, at the time of collecting failure costs, it was decided to define failure as “any incident that impeded the process of construction of the building” and quality failure as “an activity that failed to proceed as planned or, in other words, an activity that was inefficient”. The cost of delays only was considered where it affected the construction critical path. And external quality failures were included in a sense that they have been transferred to the customer.

Aoieong et al. (2002) developed a Process Cost Model (PCM) to capture the costs of quality for specific processes. The quality costs in PCM are termed “process costs”. Process costs then were divided into two groups: the costs of conformance (COC) and the costs of non-conformance (CONC) (Aoieong et al., 2002). Later, in Tang et al. (2004) to test the model for a concrete process, the following definitions were elucidated:

- Cost of conformance: “is the intrinsic costs involved for providing the finished concrete product as required in good order”.
- Cost of non-conformance: “is the costs of wasted time, materials and resources and any costs associated with the rectification of the unsatisfactory concrete product”.

The process cost is then the total costs of cost of conformance and cost of non-conformance (Aoieong et al., 2002). In Tang et al., 2004, the costs of non-conformance then were calculated for three different parts. These include: formwork placing, reinforcement placing and concrete placing. For formwork placing, the costs of non-conformance were calculated based on the estimated time and labour required for fixing each non-conformance occurrence. For reinforcement placing, “the number of occurrence of each type defects was recorded and the time and cost required for the remedial work were then estimated based on current labour rate”. And for concrete placing, based on the severity of the defects, the time and cost required to complete the remedial actions were estimated in accordance with the current labour and material rates. In this study, the term “defect” is used for collecting and calculating the non-conformance cost. But, no definition of this term is presented.

Overall, it is evident from the reviewed literature that many of the definitions are broad and may encompass several elements. However, in some cases the researchers avoid arguing and presenting the related terms and definitions in detail. The reason might be the associated difficulties with providing unambiguous and acceptable definition.

Moreover, the terms used in the studies are sometimes different from study to study which explain the different points and aspects. It becomes more confusing when in some of the studies two different terms are used for reporting the same findings.

There is not also a consistency regarding the poor quality cost elements included in the investigations. While in one investigation, for example, change order was included; in another it might be excluded from the calculations. Nevertheless, it is not always clear in some of the literature that whether an element such as change orders and waiting time are considered as poor quality cost or not.

Hence, the application of different definitions and terms for quality and poor quality cost is another reason why the reporting of poor quality costs is confusing. Some scholars (Holland, 2000; Hall and Tomkins, 2001) claim that they use a total perspective, while it could be argued that they still use a narrow definition (Josephson and Saukkoriipi, 2003). In fact, due to the presence of numerous definitions and interpretations of quality and poor quality cost concepts, the researchers may use a narrow definition and limit their study to some cost elements. Accordingly, each definition will lead to the consideration of a measurement, or metric. Moreover, they limited their measurements to visible costs of poor quality, however, many of the costs of poor quality are hidden and difficult to identify.

The definition should be clear and discuss about the aspects, which are considered as a poor quality cost in detail so that one can realize what types of costs are considered as poor quality cost. The researchers should pay attention to the fact that a clear and consistent definition of the key terms included in their investigations is a crucial prerequisite to their studies (Sörqvist, 1997). Without this clarity and consistency, interpretations of research results become problematic. The "definitional inconsistency" across the reviewed studies makes it difficult to claim a generalized statement regarding poor quality cost in construction.

All in all, different definitions were presented concerning:

(a) If just the failure costs were considered or all prevention, appraisal and failure costs or even researchers follow some particular processes.

(b) Measured cost elements, i.e. different cost elements were included in reviewed studies.

(c) Considered definitions and terms.

6.3 Methods of data collection of Reviewed Studies

The importance and effectiveness of data collection is fundamental to the overall quality of research. The validity and the quality of data are of high importance which sometimes not given sufficient attention. The quality of data is in a direct relationship with the quality of the research. If data was gathered based on the poor methods and manners this will lead to poor quality research (Carter and Fortune, 2004). Basically the following factors may influence the choice of method for an investigation: (1) the source and the resources available; (2) the time required for answering questions and conducting the study; (3) the expected response rate; (4) the expected biases; (5) the type of variable; (6) the accuracy required; (7) the collection point; and (8) the skill of the data collector.

Reviewing the current literature shows that different methodologies for data collection have been used by different researchers. For example, in the study carried out by Josephson and Hammarlund (1999), during six-month period:

> "one observer is placed at each site. The observer has no other task than to register, follow-up and describe defects occurring. By making rounds on site, the observer has daily contact with all the personnel, the building contractor's as well as the subcontractor's personnel. When necessary, the observer contacts the client, designers, material manufacturers, etc. He takes part in meetings and reads all documentation. Each observer has been educated in the method and introduced at the site. During the study the observer and the researchers have continuous contact. At special meetings, the observers compare notes".

The data collection consisted of three main parts:

- *Defect descriptions*. "Each defect is described on a special form. Approximately 20 questions are coded. They are supplemented with detailed descriptions of causes, erroneous action, manifest defect, consequences and corrective measures. The defect cost is estimated. Sketches, drawings and photographs are appended. A total of 2879 defects were registered. Some of them consisted of several similar defects".
- *Project description*. "To enable the analysis, each building project is fully described. Among other things, the project organization and the site organization changes during the process, systems for leading, planning methods, policies regarding choice of sub-contractors, etc., activities included and their interdependence, are described. Schedules, drawings, site meeting records and diary are appended. Costs and times for the whole project and for separate physical elements, activities and materials are stated".
- *Interviews*. "In each project, the research group interviews 10–15 key persons. Each interview is approximately 1 h. The interviews are tape-recorded and transcribed in full afterwards. During the interviews, the characteristics of the building project are mainly discussed".

Similar to the method used by Josephson and Hammarlund (1999) is employed by Barber et al. (2000), which they called it "work-shadowing". They shadowed key personnel such as engineers, foreman and other key operatives for a period of time. In this way, they used a form to record the main elements of each problem, the time delay it caused, the detailed resources used to rectify it and their cost categories. Later, they also supplemented the work-shadowing with regular reviews of quality problems with designers on site. After calculating the cost of each identified failure, these expressed in terms of weekly costs for each size of failure. Later, "the estimated cost per week over all sizes of failure was expressed as a percentage of the weekly budgeted cost of the specific areas work studied". However, it is not evident in this study that from what sources they extracted and calculated the costs of failures.

Abdul-Rahman (1995) used a different method. Instead of following the project personnel, they gathered data "based on discussions and interviews with key personnel and recorded information". Background information for the contract is obtained from the discussions with the main contractor's quality assurance manager, quality systems engineer, site agent and project manager. Data on non-conformance events were collected mainly from the defect notices used by the main contractor as part of its quality systems recording procedure while others were from interviews and discussions with staff who participated in this investigation. The latter relied on records from variation orders and other site instructions. The defect notice details each item of work on site that does not conform to the specifications or plan of work.

Abdul-Rahman et al., (1996) used a similar method as their previous method but with some differences. Researchers made "18 site visits during a 22-week period towards the end of construction". They gathered data during each visit from "interviews and discussions with site engineers". The costs related to each non-conformance event were estimated by "the company's quantity surveyor based on resource and material usage as obtained during the interviews". Estimates were based on information for each non-conformance event and included the quantities of material used for rework, labor and plant, and site management time.

Love et al. (1999b) gathered data from "the date from which construction commenced on site until the completion of the defects liability period". Several methods used to collect data as follows:

- *Interview*: project's client, site management team, consultants, subcontractors and suppliers were interviewed (unstructured and semi-structured). "Interviews were used primarily to determine those variables that influenced the occurrence of rework. The interviews were conducted on a one-to-one basis and were open so as to stimulate conversation and breakdown any barriers that may have existed between the interviewer and interviewee. Interviews were used to gain 1) an understanding of the constructs that the interviewee uses as a basis for forming opinions and beliefs about a particular rework event; (2) an understanding of the step-by-step logic of why and how a rework event occurred; and (3) the confidence of the interviewee".

- *Site visits*: researchers visited studied projects three times a week throughout their duration. They explained that "two block visits of four days to each project were conducted. These block visits were undertaken during times of increased site activity".
- *Direct observations, and documentary sources*: "provided by the contractor, consultants, subcontractor and suppliers were used also to derive data. Numerous other sources such as variation lists, site instructions, day work sheets, extension of time claims and non-conformances were used also to identify rework events and determine any effect on project performance in terms of time and cost".

In Tang et al., (2004) "the site engineer was responsible for providing the CONC data". For reinforcement placing process "a form containing a checklist of all the common defects was then designed to facilitate the site staff in the data collection process. The number of occurrence of each type of defects was recorded and the time and cost required for the remedial work were then estimated based on current labour rate". However, due to lack of enough human resources to capture the non-conformances "only those discovered during the final inspection by the resident engineer on each floor" were captured. For the concrete placing process, "based on the judgment of the resident engineer, concrete honeycombs that required remedial works would be marked and photographed".

The major method of data collection in both Love and Edwards (2004) and Simpeh et al. (2012) was based on a questionnaire survey, but with some differences. Love and Edwards (2004) explain that:

> "Rather than developing a questionnaire survey that sought to elicit general opinions about rework, respondents were asked to select a recently completed project most familiar to them and answer questions about the perceived causes of rework, associated costs, and the project management practices implemented".

And in Simpeh et al. (2012) the method of data collection was explained as:

> "The data for this study was collected through a questionnaire survey from construction professionals including architects, contractors, consulting engineers, quantity surveyor and project managers…the questionnaire was designed to determine, inter alia, perceptions of respondents regarding the project characteristics, organizational management practices, causes of rework, impact of rework, measurement of rework cost and rework containment strategy".

This overview shows that there are a wide range of data collection methods and approaches used by researchers. Methods and approaches used by researchers are different in terms of the following points:

(a) If they have occurred in parallel with the construction projects or they have been made for the completed projects.
(b) Whether it has conducted oral interviews and/or written questionnaires, made direct observations, analyzed historical project documentation or studied failures gathered from failure's documentation.
(c) Whether it has made occasional visits to the construction site or made continuous monitoring (Full-time observation).
(d) If the data collection was carried out by individuals operating in projects or by outside observers.

This review shows that researchers utilized the following methods of data collection or a combination of them as major methods of their studies:

a. Direct observations:

   i. Full-time monitoring
   ii. Occasional visits to the site

b. Oral interviews
c. Written Questionnaires
d. Examination of historical project documentation
e. Examination of gathered failure in a failures' documentation

Participant observation is considered as one of the best-known methods of data collection (Bryman, 2008). This method is expensive and needs more time in comparison with other methods especially when it comes to use of the training observer. Provision of training to observers by offering practice sessions not only help the observers on how to collect data in the right way but also ensure that all observers are rating their observations in the same way, thus ensuring that the data are reliable. In addition, utilizing a full-time direct observation helped them to observe poor quality related costs in their natural setting, thereby providing a richer set of data. When an observer visits construction site is likely to better understand the nature of the failure and associated costs after directly observing the construction activities, workers and processes in comparison with relying solely on documents or key informant interviews. Furthermore, it may reveal such failures and failure costs many informants may be unaware of or unable to describe adequately.

Regarding the direct observation method that some of the researchers made occasional visits to the site, the quality of data might not be as high as a full presence on the site because by fully presenting on site firstly, a more comprehensive and clearer picture emerges of the research setting by recording more data (Geertz, 1973; Burgess, 1984). Secondly, in full-time observation, the observers becomes a participant in the project or culture or context being observed which help them to record the more accurate data as they can follow the natural behaviors of the project participant.

In those studies examining the project documentation as the method for data collection, the researchers are not able to control the quality of data being collected and must rely on the information provided in the document(s) to assess quality and usability of the source(s). In addition, in those studies that the data are collected for completed projects/processes, they should rely on the memory of the project participants. Because of the above-mentioned reasons, it should not be used as the major method of data collection for poor quality cost, despite the fact that it is typically less expensive than collecting the data by other methods such as direct observation.

Some of the studies have relied primarily on after-the event interviews with key participants involved in the project to collect data. The major drawback, in this case, is that the interviewees may forget important activities that led to poor quality which in turn affect the quality of their data.

Further drawback of those groups of studies that they mainly rely on the interviewing and using questionnaire for the data collection is that the participants who take part in the interview and questionnaire may not be willing to answer the questions. They might not wish to reveal the information or they might think that they will not benefit from responding perhaps even be penalized by giving their real opinion. Therefore, the quality of data is probably not as high as with alternative methods of data collection such as direct observation. Instead, it seems more logical if they use these methods for gaining insight and context into the issues.

In short, there is not any consistency regarding methods of data collection. Some studies made random observation and others make more systematic and resource demanding investigations. Some studies are questionnaire investigations that rely on the attitudes of different individuals, while other studies use more factual methods for data collection, e.g. direct observations of what really takes place. Consequently, the qualities of data obtained are different based on the methods used by researchers.

Table 1. Summary of aims, definitions, and methods of data collection and findings of reviewed studies

Authors	Aims	Definitions	Methods	Findings(poor quality cost)
CII (Burati and Farrington, 1987; Burati et al, 1992)	A quality performance tracking system has been developed to provide for the quantitative analysis of certain quality-related aspects of projects, by systematically collecting and classifying costs of quality in nine new construction and renovation projects (industrial buildings) in the US.	Deviations: illustrate that a product or result that does not fully conform to all specification requirements does not necessarily constitute an outright failure. Deviation Costs: The sum of those costs, including consequential costs such as the rejection or rework of a product.	"The researchers studied the project documentation for completed projects and supplemented with interviews when it was required".	88-1463 deviations were recorded per project. 0.4 to 26.0% of the construction cost, including alterations (an average cost of quality deviations found to be as high as 12.4% of the contract value).
Chalmers I (Josephson, 1994; Augustsson et al., 1989)	"The purpose of this study was to stimulate improvements by indicating where preventive measures are most effective as well as how to perform them".	Defects: a non-desired condition in the product or process. (The non-fulfillment of intended usage requirements). Defects Cost: "The value of resource consumption for rework as a consequence of a defect".	The researcher "appointed a trained observer over a two-year period who undertook direct, regular observations and interviews".	"1460 defects were registered, analyzed and described in detail". Internal failure costs correspond to approximately 6 % of production cost.

Table 1. Summary of aims, scopes, definitions, and methods of data collection and findings of reviewed studies

Authors	Aims	Definitions	Methods	Findings(poor quality cost)
Abdul-Rahman et al. (1996)	This study describes the use of the quality cost matrix developed by Abdul-Rahman (1993) to capture the cost of non-conformance during the construction of a water treatment plant and a bridge.	Non-Conformance cost: All costs incurred by the business because the product was not designed, produced or serviced in a perfect manner during the initial cycle.	"A total of 18 site visits were made during a 22-week period towards the end of construction. During each visit information was gathered mainly from interviews and discussions with site engineers "and grouped into 12 classifications of non-conformance in a matrix model.	62 non-conformances were identified on-site. "The total costs of non-conformance incurred were 5-6% of the tender value ".
Abdul-Rahman (1995)	Describes the use of a matrix which has been developed to capture the cost of quality during a high way project. A case study is used to illustrate the practicality of the matrix in capturing relevant information from a main contractor.	Failure cost: the cost incurred to rectify a departure, which may be in the form of an imperfection, non-conformance or defect, to meet established requirements Non-conformance costs: include those incurred for rework, repair, loss of client's goodwill, liquidated damages and litigation.	The researcher made discussions and interviews with key personnel and recorded information and grouped them into 12 classifications in a matrix model. (Data on non-conformance events were collected mainly from the defect notices used by the main contractor as part of its quality system recording).	"A total of 72 non-conformances were gathered by the end of investigation of which 59 were considered for analysis. The total cost of non-conformance was 5% of the total cost (tender value)".

Table 1. Summary of aims, definitions, and methods of data collection and findings of reviewed studies

Authors	Aims	Definitions	Methods	Findings(poor quality cost)
Chalmers II (Josephson and Hammarlund (1996, 1999))	"The research presented in this paper identifies, analyzes, and discusses the causes, magnitudes, and costs of defects in seven new construction and renovation projects managed by seven different companies in Sweden".	Defects: a non-desired condition in the product or process. (The non-fulfillment of intended usage requirements). Defects Cost: "The value of resource consumption for rework as a consequence of a defect".	"The researchers trained and coached observers, who were full-time at each site. Observations, interviews and studies of project documentation".	2879 errors recorded. Failure cost ranged between 2.3 and 9.4% of the construction cost.
Willis and Willis (1996)	"Describes the importance of QPMS. How it should be implemented and, an illustration of the quality costs resulting from a multi-million dollar heavy industrial project procured by a design and construct system".	Deviation correction: when the work has to be carried out again to meet the requirements or expectations.	Personnel were responsible for reporting deviation corrections.	The cost of prevention and appraisal plus the cost of failure and deviation correction was 12% of total labor expenditures for design and construction. This was consisted of 8.7% prevention and appraisal and 3.3% deviation correction.

Table 1. Summary of aims, definitions, and methods of data collection and findings of reviewed studies

Authors	Aims	Definitions	Methods	Findings(poor quality cost)
Love et al. (1999b); Love and Li, (2002)	"Quantification of the causes, magnitude and costs of rework in two new construction projects in Australia, including an apartment block (48 weeks) and an industrial building (38 weeks)".	Rework: unnecessary efforts of correcting construction errors Rework costs: "Total cost derived from problems occurring before and after a product or service is delivered".	"The researchers made three visits per week during construction. Interviews, observations and studies of project documentation, meeting and interview with site management". Defects Collected on site during the construction processes.	383 events were recorded. "In a building project the cost of rework including alterations was found to be 3.15% of the contract value, and in one industrial project it was 2.40 %".
Barber et al. (2000)	The research objective was to provide some overall quantification of the scale of cost involved for the element of work examined in two major road projects in the UK and to raise quality consciousness in the process of managing change.	Internal failures: cost incurred due to scrapping or reworking defective product or compensation for delays in delivery. External failures: cost incurred after the delivery of a product to the customer-costs of repairs, returns, dealing with complaints and compensation	"Key personnel on-site were shadowed for a period of time" and the quality problems encountered were recorded.	A total of 238 incidents were recorded. Failure costs were about 16% and 23%of the weekly budget.

Table 1. Summary of aims, definitions, and methods of data collection and findings of reviewed studies

Authors	Aims	Definitions	Methods	Findings(poor quality cost)
Hall and Tomkins (2001)	**“This paper presents a methodology for assessing the complete cost of quality for construction projects and reports on the findings of a building project in the UK on which the methodology was piloted”. The building was a new construction office building in the UK (38 weeks).**	**Failure: any incident that impeded the process of construction of the building. Quality failure: an activity that failed to proceed as planned or, in other words, an activity that was inefficient.**	**The site staff were required to monitor quality failures on site through self-monitoring and observation. The project manager, site agent, quantity surveyor, and junior staff were all involved in recording and collecting data.**	**166 events were recorded. Quality failure costs reported 5.84% of the contract sum whereas costs of prevention, appraisal and other activities were reported 12.68% of the contract sum.**
Tang et al. (2004)	**“The objective of this paper is to report the findings of these two case studies in which the PCM is used to capture quality costs”. Two case studies including a 38-story building project and one civil engineering project in Hong Kong.**	**COC: is the intrinsic costs involved for providing the finished concrete product as required in good order. CONC: is the costs of wasted time, materials and resources and any costs associated with the rectification of the unsatisfactory concrete product.**	**The site engineer was responsible for providing the cost of non-conformance data during the “concreting process”. Number of occurrence of each type of defects was recorded and the time and cost required for the remedial work were then estimated based on labor rate.**	**In building project the costs of non-conformance decreased from 0.48% of the total process costs in the 21^{st} floor (1^{st} cycle) to 0.43% at the end of project in the 38^{th} floor (18 cycle). In civil engineering project, costs of non-conformance declined from 3.55% (1^{st} cycle) of the total process costs to 0.03% (30^{th} cycle).**

7 Discussion and Concluding Remarks

The findings of different investigations about poor quality cost in construction are often compared with each other in discussions of scientific studies, though they have different focuses, approaches, definitions, cost elements, measurement methods and scopes. The result is a great confusion about poor quality cost among construction researchers and practitioners.

By considering studies about poor quality cost in construction, some major issues can be highlighted. One of the interesting points among the literature is that in those studies which aim at measuring and capturing poor quality cost and determining the size of poor quality cost, the numbers of recorded failures are much more than other groups. Moreover, they also employ more powerful methods of data collection in comparison to the others.

Another surprising point is that just a few numbers of literatures quantify the cost of poor quality in a comprehensive and reliable manner. The rests are about getting management attention, testing a quality cost model and provide guidance on the utilization of that model and follow up.

While all scholars within the building and construction industry agree that the costs are too high, there are disagreements on which cost elements and what methods and definitions should be used. The accuracy of the measurements is not always as it was expected, which has resulted in misleading comparisons. Moreover, there is often much disagreement when it comes to deciding which cost elements should be regarded as being associated with poor quality. Different terms and definitions are presented in the literature sometimes even for referring to the same situation they used different terms (Love and Edwards, 2005). However, these terms are “emotive terms” Macarulla et al. (2013) and researchers must be careful when practicing them; otherwise, the results create confusion and misunderstanding for the readers and users. Obviously, this inconsistency about the terms and definitions makes it difficult to find a rigorous definition of quality related terms and in particular poor quality cost in construction.

Besides, several different methods have been used and every method is usually adjusted according to their purposes and aims, which results in various conclusions. In fact, different methods and grouping are used and the various costs and elements are defined in different ways in accordance to their objectives. For example, some papers present a detailed account of the methodology of poor quality cost collection, though some of the authors give only a brief outline sufficient to explain their results. Also, a variety of elements are included or deemed unimportant and left out the calculations.

In addition to these points, the selected bases for poor quality cost calculation vary as well, which causes an inconsistency in poor quality cost figures and makes it even more difficult to compare the results of studies. One of the most widely used is the calculation of poor quality cost as a percentage of total cost of the project; however, other bases such as weekly or daily cost of the project or labor cost or contract value are used as well.

Adding to these differences, there are still wide variations in published researchers, because different researches are conducted in various countries and every country has its own “regulations, culture, contractual arrangement as well as levels and interpretations of quality” (Love et al, 1999b) so different elements are included.

Moreover, it is also evident from the literature that the studies are different concerning the scopes, i.e.:

a) Which type of the project the study is conducted on i.e. whether they conduct they study for building projects, infrastructure projects, heavy industrial projects or road and highway project, etc.

b) Which stages of the projects they choose to study the poor quality cost i.e. design, construction and/or maintenance or the whole life cycle or specific processes.

Another point is that some of the studies collected data mainly from the noticed by the main contractor. However, in most developed construction markets, such as the UK (Barber et al., 2000 and Abdul-Rahman, 1993), US (Burati and Farington, 1987) and Australia (Love and Li, 2000), where the cited studies were conducted, main contractors perform very little physical work themselves. In these areas, the main contractor, however, tend to manage and co-ordinate the input of a wide range and number of subcontractors and suppliers (Harvey and Ashworth, 1993).

Despite the fact that these studies have had different aims, methods and definitions, all indicate the high level of waste in terms of poor quality cost in the construction processes. However, in order to make the comparison between the findings, it is essential that the classification and bases of poor quality cost data are relevant and consistent with other so that comparisons may be made between their findings. But in case of poor quality cost for construction, the results are proliferation of uniquely defined cost elements, which preclude comparison of data from different sources. It is also impossible to make any conclusion as to which study is superior and it must be concluded that any method in the studies has a chance to succeed if it suits the purpose of that. However, based on the purpose to use the result the references to the studies should be done more carefully.

Overall, to a certain extent the wide array of factors regarding construction poor quality costs literatures and their different reported results has contributed to blur the boundaries and create confusion about the poor quality costs. The users should be well-aware of using them and for what purpose wants to use the reported findings. Certainly what this literature review illustrates is that one must be careful when comparing and referencing the findings of previous studies as they may not be entirely comparable with one another. Moreover, lack of uniformity in current literatures indicates that this research area is still far from maturity and needs more attention from researchers and practitioners. It should be noted that the results of the reports can be compared and contrast to each other and use for benchmarking action if the same definitions, methods, aims and other situations are met, otherwise, the only alternative would be to evaluate every reports so that at least it can be understood and utilize for the right purpose.

Clarity of description and standardization of definitions as well as utilizing powerful methods for data collection are critical to the assurance of data quality and to the avoidance of interpretative errors when using data. So, the present author suggest that may be one alternative to solve the above-mentioned problems is to standardize the measurements systems, at least for the some levels, which obviously entails standardized and unambiguous classification of quality related costs' definitions. Although it is likely that this takes time for users to adjust to standardized methods and definitions, but the outcome is to the better of the entire construction industry.

By introducing a standard set of definitions and methods of data collection, it is also possible to benchmark the different poor quality cost measurements and comparing the findings with other industries and also other construction projects for evaluating the performance.

7.1 Future Research

This review shows that this research area is still needs more attention from both construction professionals and academia to enhance current knowledge and tackle the problems. Future research must start with explicit and unambiguous definitions of poor quality cost and standardized methods of data collection. While there is no consensus in the literature with regards to definitions, researchers need to clearly present their key terms and definitions and their key terms of poor quality cost and apply these definitions when collecting data. Researchers should also take into account that the quality of their data has a direct relationship with the methods they use. Of that reason, future studies must be based on more reliable and systematic methods of data collection particularly if the purpose is to accurately calculate the cost associated with poor quality.

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Paper 2:

Poor Quality Costs in BIM and Lean Literature: A Review of Evidences

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1 Abstract

The concepts of Building Information Modeling (BIM) and Lean Construction (LC) have gained widespread attention in recent years among construction professionals and researchers. As a result, numerous books, articles and reports have been published about both BIM and LC. Several promises have been presented concerning their potentials in reducing the problems associated with poor quality cost as a common aspect between them. This paper reviews the findings of previous researches on BIM and LC linked with reducing poor quality cost. The aim was to carry out a review of literature and to extract previous findings from the most relevant literature. The review was to focus largely on journal literature, whilst also supplementary search for relevant books and conference literature has been conducted. In this paper, 90 articles on BIM and LC were retrieved. Fifty (50) studies met the criteria for relevance and were assessed to provide an overview. The findings show that despite the presence of numerous promises in favor of BIM and LC to reduce the poor quality cost, a few or none has followed up and confirmed by evidences.

Keywords: Poor Quality Cost, BIM, Lean Construction, Evidences

2 Introduction

Over the past several years, it has been well documented that the construction industry produces tremendous amount of wastes as a result of poor quality activities. This is of high significance since construction industry in most of the countries is one of the important industries in terms of high contribution to their economy. There are several ways construction firms are trying to reduce this amount of wastes. Building Information Modeling (BIM) and Lean Construction (LC) are the two most significant alternatives.

That is, BIM and LC have gained widespread attention in recent years among construction professionals and researchers. Even though BIM and LC are two different initiatives (Sacks et al., 2010), both have the potential to increase the level of quality, hence decrease the costs of poor quality. Several "promises" about both BIM and LC have been presented by researchers and professionals concerning their potentials in reducing the problems associated with poor quality cost.

Such promises and sources provide a coherent and seemingly convincing argument in favor of implementing BIM and LC in the construction projects. Nevertheless, their effectiveness is not completely proven (Jung and Joo, 2011; Matthews et al., 2000). Hence, many organizations have taken a "wait-and-see attitude" about BIM and LC, looking for evidences to validate their benefits and return on investment. For the users who are to adopt BIM and LC need to be encouraged by means of empirical and first-hand evidences about their realistic potential in reducing problems. Investors also need to justify their investment of time and budget in BIM (Coates et al., 2010) and LC by observing the evidences of their benefits.

Therefore, the primary purpose of writing this paper is to review the evidences of poor quality costs in BIM and LC literature and develop of an overview on how poor quality cost is used in BIM and LC literature.

In line with the main purpose of the paper, the following research questions will be explored:

1. How are poor quality costs used in BIM and Lean literature?

2. What are the implications and evidences of poor quality costs in BIM and lean literature?

The paper is structured in four major parts. First, the methodology for this literature review is presented. Second, theoretical backgrounds and concepts about three major themes including poor quality cost, BIM and LC are presented. Third, evidences of poor quality cost reduction in BIM and LC literature are reviewed. And finally, discussion and concluding remarks are drawn.

3 Methodology:

Relevant papers were initially gathered from multiple databases and literature collections of published, peer-reviewed research papers and reports. Keyword bibliographic searches were conducted in electronic databases including Emerald, American Society of Civil Engineers (ASCE), Science Direct, ProQuest, Taylor and Francis and Google Scholar. The search was started with some of major keywords related to the topic including combinations of ‘Poor quality cost/cost of poor quality’, ‘failure cost’, ‘quality cost’, ‘rework cost’, ‘defect cost’, ‘non-conformance cost’, ‘BIM’, ‘Lean Construction’ and ‘construction industry’. By reviewing gathered papers in the literature, a few new keywords were obtained later and the search was expanded. Finally, search results were augmented through back-referencing potentially relevant citations in the identified papers. The result includes 90 literatures and covers more than 10 journals and conference proceedings.

Inclusion and Exclusion Criteria:

The identified studies were filtered and categorized by firstly reviewing the abstracts; subsequently the studies were narrowed down according to the following criteria:

1. The English reported literature, which published no earlier than 1980.
2. The thesis focused on the poor quality cost, BIM and Lean construction literatures concerning the construction industry.
3. Given the purpose of the thesis the papers reporting poor quality cost in the construction and civil engineering projects are included for the main discussion.
4. To explain the concept of poor quality and poor quality cost, some of the most relevant citations in peer-review journal papers related to poor quality cost were supplementary reviewed.
5. Newspaper’s articles, editorials, commentaries, letters to the editor and news items were excluded.

By applying these points, the number of reviewed papers was reduced to fifty (50). In the next step, full papers were reviewed and grouped into three major categories. One group included the literature related to BIM and another group consisted of literature concerning LC and the next group was devoted to the literature about poor quality cost in construction. Finally, the promises in favor of both BIM and LC were categorized and the discussions related to poor quality cost in those literatures were extracted.

4 Theoretical Background:

This review focuses on three major themes: Poor Quality Cost, Lean Construction (LC) and Building Information Modeling (BIM). So, in this section a brief overview of these terms is presented.

4.1 Introduction to quality related terms

In this section, in order to present a better view of the discussed concepts, the major quality-related term are briefly presented.

4.1.1 Quality management

The concept of quality has several different meanings ranging from, for example, "freedom from product deficiencies" (Juran, 1985) to "conformance to requirements" (Crosby, 1979). Each definition is, in turn, very broad and might include several different concepts and elements. Hence, it can be consider as a vague concept. Moreover, some believe that good quality means a perfect product without defects, and some believe that it is products delivered in time. This means that quality is abstract and subjective. These variations create confusion and pose problems for those who aim to deal with it. Since definitions of good quality differ, definitions of poor quality, and poor quality costs, differ as well. However, they can be considered as a valuable indicator for performance (Abdul-Rahman, 1997).

The role of quality management has to provide an environment that facilitates the effective deployment of related tools, procedures and techniques (Harris and McCaffer, 2001) which, in turn, lead to operational success for an organization.

One of the major benefits of quality management, which is often quoted in the literature, is to "maintain the quality of construction works at the required standard so as to obtain customers' satisfaction that would bring long term competitiveness and business survival for the companies" (Tan and Abdul-Rahman, 2005). Excellence in quality management is a requisite for construction organizations, who seek to remain competitive and successful. The challenges presented by competitive construction markets and large projects that are dynamic and complex necessitate the adoption and application of quality management approaches.

4.1.2 Quality Cost

To benefit from the total quality management application, it must be measureable. One of the tools that give us an opportunity to measure quality is the quality cost (Juran 1988; Crosby, 1984). Quality cost can be grouped into different categories. One of the widely-use categories which is known as PAF has two major parts. The first part includes the cost of quality management which consists of prevention and appraisal costs and the second part is failure cost also known as poor quality cost which consists of internal failure, external failure and intangible quality costs.

Abdul-Rahman (1993) has defined quality cost as: "all costs associated in managing project quality and costs derived from non-conformance incurred once a project progresses". Management of quality issues refers to prevention and appraisal costs and non-conformance cost also known as poor quality cost refers to those costs incurred due to rework, repair, loss of client's goodwill, liquated damages and litigation (Abdul-Rahman, 1993). According to Low and Yeo (1998) quality cost is the factor that differentiates between the costly way and the beneficial way of gaining quality.

Using and measuring quality cost can bring several advantages (Abdul-Rahman, 1997; Freiesleben, 2005). For example, it is seen as a useful indicator of performance (Abdul-Rahman, 1997). Collection and use of quality costs are useful tools to support management and are accompanied by improvement of quality.

Nonetheless, "there is no absolute rule in quality costing" (Abdul-Rahman, 1993), each construction organization may decide to develop and adopt its own classification of quality cost due to limitations in existing systems and for practical reasons. Hence, there are likely different ways for measuring and capturing quality cost.

4.1.3 Cost of Poor Quality (COPQ)

The cost of poor quality reflects a portion of the total quality costs. Calculating the cost of poor quality allows an organization to determine the extent to which organizational resources are used for activities that exist only as the result of deficiencies that occur in its processes. According to Abdul-Rahman (1993) measuring and identifying poor quality cost and their related causes reveal the failure areas and allow them to prevent their repetition for similar future work.

Poor quality cost measurement also can be a useful tool in decision-making support for an organization's improvement efforts (Plunkett and Dale, 1987). Having such information also allows an organization to determine the potential savings to be gained by implementing improvement tools such as BIM and LC. Looking at poor quality costs is one way of understanding the level of quality, i.e. finding out how much is spent / lost due to lack of good quality.

Some instances of poor quality, e.g. scrap, rework, and delayed payments, are fairly easily found and their effects (costs) are known and measured (Abdul-Rahman, 1993). However, most of the poor quality costs are difficult to identify and calculate because many are 'hidden', i.e. not reported in the regular accounting system, or even known. One example of a hidden poor quality cost is the cost for having inefficient routines.

4.1.4 Uses of Cost of Poor Quality measurements

Measuring Poor Quality Cost (PQC) is a good starting point for the improvement work. It enables managers to measure quality improvement through identifying and highlighting various situations that will cost them in the wastage of time, unnecessary service charges and materials usage (Krishnan, 2006). Information gained through measuring PQC provides a corporate basis for deciding on the significance of alternative improvement actions (Sandholm, 2005).

PQC measurement also creates the possibility of benchmarking as a point of reference for managers and helps them to compare their outcomes with best practices and search for improvement actions. If measures are undertaken, benchmarking can be taken into consideration for poor quality cost reduction which in turn provides further benefits such as performance improvement and customer satisfaction (Andersen and Moen, 1999). This benchmark also can provide useful comparative data and would be helpful especially for those organizations undertaking several large projects applying BIM or LC.

In short, the advantages of its measurement can be summarized as the followings:

- Performance measurement and Continual improvement (Dale and Plunkett, 1991)
- Higher standards
- Improved systems and procedures
- Improved motivation (Dale and Plunkett, 1987)
- Lower costs and bottom line savings
- Provide management with the information about the "potential impact of poor quality on financial performance" (Morse et al., 1987)
- Identifying poor quality related activities that are more beneficial in reducing quality costs (Morse et al., 1987)
- Taking remedial actions to prevent recurrence (Dale and Plunkett, 1991)
- Prioritizing quality improvement activities (Morse et al., 1987)
- Comparison with other parts of the business or with other businesses (Dale and Plunkett, 1987)

4.1.5 Cost of Poor Quality in Construction

Poor quality costs in construction and civil engineering projects can be serious due to the variety of risk factors (Abdul-Rahman, 1993). A numbers of attempts have been performed to capture and measure poor quality cost in construction. For example, in a study done by Burati and Farrington (1987) a quality performance management system (QPMS) was developed to track the cost of quality for nine construction projects of varying type and size. For all nine projects, quality deviations found to be as high as 12.4% of the contract value. Josephson et al. (2002) studied seven construction projects managed by seven different companies in Sweden. They recorded 2,879 errors or defects and the costs of rework were 4.4% of the construction values for the observation period.

Poor quality cost in construction-related literature is also characterized with different terms such as: "quality deviations" (Burati et al. 1992), "non-conformance" (Abdul-Rahman, 1993), "defects" (Josephson and Hammarlund, 1999), "quality failures" (Barber et al., 2000), and "rework" (Love and Li, 2000; Josephson et al., 2002). These terms mean differently in some references, though in some cases the different terms refer to the same situation. And there is no agreement among the researchers about the terms and their definitions and methods of data collection; however, all of them declared the high costs of poor quality.

4.1.6 Causes of Poor Quality in construction and civil engineering projects

Several attempts have been made to identify the causes of poor quality in construction. Even though researchers have applied different methods and definitions, all indicate the problems associated with traditional way of undertaking projects such as the problem in communicating design intents from owner to design team. For example, Abdul-Rahman (1993) indicates three different groups as the sources of poor quality in civil engineering projects which include:

- Project appraisal: refers to failure in understanding the project needs and requirements
- Design: refers to the problems related to design process such as: the incomplete information, changes in design, design mistakes, client's influence, and communication problems.
- Construction: refers to the problems related to construction process such as: labor, material, poor planning, client's influence and project uncertainty.

Love et al. (1997) categorize the causes of rework into three major groups. These include the followings:

- People: communication, skills, goal divergence, resources, coordination, inexperienced personnel, integration, collaborative problem solving, decision making.
- Design: procurement, customer needs, design brief, drawings, specifications, information platforms, checking procedures.
- Construction: program, non-implementation of quality assurance, weather, damage by others, fabrication, Set-out changes/ errors, site conditions, information bottlenecks.

In another study undertaken by Love and Li (2000) "changes initiated by the client and end user" as well as "errors and omissions in contract documents" have been found as the major causes of rework.

According to Burati et al. (1992), 79% of total deviation costs were related to design procedure and 17% associated with construction course. The Building Research Establishment (BRE, 1982) also found that 50% of errors initiated in design stage and 40% in the construction stage.

In order to save cost, time and the other resources to further use them in other areas, the above-mentioned causes of poor quality should be identified and diminished.

4.2 Building Information Modeling (BIM):

There is a growing body of researches about BIM as an emerging topic and several definitions have been presented (Succar, 2009; Van Nederveen et al., 2009; Demchak et al., 2008; Eastman et al., 2008). According to National Building Information Modeling Standard Committee (Cited in Leite et al., 2011) BIM is "a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward".

A primary problem in the conventional way of managing construction projects is that architects and engineers are often using the traditional design and documentation tools, which do not automatically prevent certain types of errors and omissions from existing in the documents (Bryde et al., 2013). Contractors and the design team are also being pushed to deliver faster. These elements combined result in a lot of request for information (RFIs) and change orders in the field. RFIs are too huge for the designers to keep up with, and construction documents for today's buildings are very complicated and only show a single aspect of the project. The result is that information is not flowing properly between members of the team. As a result, things fall through the cracks and someone gets blamed for not doing his/her job.

However, a BIM project differs from traditional fragmented practices of numerous individual sheets of drawings with lines, arcs, and texts in multiple documents (Bryde et al., 2013). Instead, it builds digitally as a database in BIM software. Instead of having to look in separate drawings, schedules and specifications for the information on a particular element, all the information is built into an intelligent object in a BIM model. Once placed in a BIM model, it would automatically represent its plan, elevation, section, details, schedules, 3D rendering, quantity take off, budget, maintenance plan, etc. As the design changes, the object can adopt itself to adjust to the new design. This opens up enormous potential for exchange of information between project team members and provides a more collaborative and cooperatives environment in comparison with the traditional paper-based manner (Bryde et al., 2013).

BIM starts early in the schematic design phase, during this stage, the owner's intent and requirements are collected and documented. The information is typically formalized in the owner's project requirements document. The information gathered here is used to initiate developing the building model. This model is typically three dimensional and is carried according to construction contract (bid) documents. The model must include all disciplines, such as: structural, architectural, plumbing, electrical, and fire suppression systems and so forth. This building model typically does not constitute complete coordination of all disciplines, but provides significantly improved construction documents over the traditional delivery method (Eastman et al., 2011).

The next phase of BIM comprises three-dimensional construction coordination. This is typically performed by the trade contractors, with the construction manager or a BIM consultant facilitating the BIM process. Each building system trade contractor either leverages "in-house" three dimensional modeling software and personnel or hires an outside BIM consultant to create 3D model of their associated systems. As the systems are developed, each contractor submits a progress update to the BIM facilitator. The systems are merged a common model for coordination. Clash detection software is used to highlight the coordination problem areas. The trade contractors' work through the conflicts until the model is "clash free." The building systems models are then deployed to the fabrication shops so the construction process can begin (Eastman et al., 2011).

The final phase of BIM enhances the information in the model so that it can be used through the life cycle of building. A finalized BIM model provides an accurate source of information about the as-built spaces and systems. It also serves as a useful tool for maintenance of the building. The information added to the model during the final phase can include any of the following: equipment submittals, testing, adjusting, balancing reports, maintenance manuals, control diagrams, equipment part ordering information, valve schedules, equipment bar coding, preventative maintenance schedules, equipment startup procedures, and owner training videos. Although this phase of the BIM process is often neglected, it is the most important phase, since it takes through the life cycle of the building. The key to the success of this phase is leveraging cutting edge technology and equipping the owner with the necessary training to fully utilize the building information that is in the model (Eastman et al., 2011).

4.2.1 History and basic features of BIM:

Building Information Modeling (BIM) firstly introduced in the mid-1980s. In 1986 Graphisoft introduced their first "Virtual Building Solution" known as ArchiCAD (Kmethy, 2008). This innovative software allowed architects to create a virtual, three dimensional (3D) representation of their project rather than the standard two dimensional (2D) objects created in challenging computer aided design (CAD) programs of the time. This was important because architects and engineers were then able to store large amounts of data sets 'within' the building model. These data sets include the building geometry and spatial data as well as the properties and quantities of the components used in the design. However, BIM recently has gained striking popularity within the Architectural, Engineering and Construction (AEC) industries (Eastman et al., 2008).

In comparison, designers using standard CAD applications required countless specification sheets in order to convey all the required information pertaining to the project. The creation of a digitally constructed virtual building model, along with its associated data, is known as Building Information Modeling. Building Information Modeling (BIM) can be defined as the creation and use of coordinated, consistent, computable information about a building project in design – parametric information used for design decision making, production of high-quality construction documents, prediction of building performance, cost estimating and construction planning (Eastman et al., 2008).

Since the BIM software architecture is based on parametric modeling the geometric consistency and integrity of the building model is maintained in spite of any changes or modifications that may have been made in it. Understanding the concept of these parametric objects is key to understanding what a building information model is and how it differs from traditional 2D design. A parametric object consists of a series of geometric definitions and their associated data and rules. In addition, these geometric definitions are integrated non-redundantly and do not allow for inconsistencies between the model and its associated data set. This means that any changes made directly in the model will result in an equal change in the data set associated with the model (Eastman et al., 2008).

4.2.2 Challenges of BIM

BIM has been identified and mentioned by several professionals and academia as a tool for decreasing wastes such as rework in building design and construction (Azhar, 2011; Eastman et al., 2008). However, its effectiveness is not completely proven (Jung and Joo, 2011). There are a number of challenges regarding BIM and its adoption and implementation in construction industry. Different authors propose different challenges and obstacles such as:

Ambiguous nature of BIM

BIM means different things to different people (Aranda-Mena et al., 2008). Evidently different organizations and people create their own definitions of BIM, based on the specific way they work with BIM. Thus, it is evident that there are differences in the way BIM is perceived by both different individuals and organizations within the construction industry. As a result, it might be difficult to come up with a common definition of BIM for the entire construction industry. In other words, there is confusion concerning what BIM is, and what BIM is not. This can lead to misunderstandings concerning expectations from different stakeholders involved in construction projects where BIM is utilized (Abbasnejad and Izadi moud, 2013).

It is evident that not only our perceptions from BIM defer greatly from one person to another, but also our expected outcomes of using BIM defers due to many reasons; having different definitions or unfamiliarity with all BIM's potential uses may be a result of having different expectations (Abbasnejad and Izadi moud, 2013).

Expertise

As it is mentioned earlier, the concept of BIM is new to some people, and the construction companies found it difficult to implement it. BIM was considered to be a complex and delicate system. People in the construction industry lacked expertise and knowledge to fully put into practice this new concept. Therefore, they must have training prior to starting work with BIM (Olatunji, 2011; Arayici et al., 2011).

Resistance to Change

The culture of implementation determines the effectiveness of a new concept. For incorporating BIM, an open-minded culture is required. In the construction industry, where project managers spend most of the time on-site, they have the liberty to work in their way. In the case of BIM, however, these project managers need to adhere to strict guidelines and processes. Therefore, there is resistance to change (Azhar, 2011; Arayici et al., 2011).

Management of Information

Another challenge that construction organizations and managers face is to manage resource and information, after the complete implementation of BIM and network-based integration. Construction organizations that are implementing BIM have to ensure that the suppliers and subcontractors follow suit. This involvement and implementation of

BIM by suppliers and subcontractors will lead to management of more information. So, mapping and management of resources should be done in accordance with these changes (Azhar, 2011).

Perceived Costs

In addition to the above-mentioned points, what proves to be a roadblock in BIM adoption is the price of the software and hardware applications, training and services as well as incompatibility with other software (Olatunji, 2011).

New processes and change

As the last but not the least factors, the managers and organizations decide to implement BIM has to change the work processes (Hardin, 2009; Arayici et al., 2011). The company, in entirety, has to be aligned to their value chain. For making necessary changes in the process, cost will be incurred. In the meantime, there is a need for an effective change management model consists of re-orientation of management strategies, training, staff motivation, utilization of suitable technologies and forming marketable products (Olatunji, 2011).

More often, one or a combination of these issues inhibits the building industry from more productive, efficient uses of technology in the form of building information modeling.

4.2.3 Benefits of BIM

There are numerous benefits of BIM during all four phases of construction projects (Pre-construction, design, construction, post-construction).

In the pre-construction stage by using BIM, building owners can estimate, before the start of actual construction of the building, whether the proposed building design is financially feasible. If a particular design is in excess of the owner's budget, the owner can easily propose for a new design that can be built within a given cost and time budget.

During the design phase, BIM visualizes the design and offers accurate extraction of 2D drawings at any stage of the process. This will improve the integration between various involved members in the design phase, and increase the sharing and reusability of design information. Hence, decreasing the numbers of change orders made by owner in comparison with the traditional ways of undertaking construction projects. Design visualization also allows for better cost estimates and budget control (Azhar, 2011).

In addition, BIM provides the ability to incorporate the thoughts and ideas of the greater supply chain. It provides the potential for a virtual information model to be handed from design team to contractor and subcontractors and then to the owner, each adding their own additional specific information and tracking of changes to the single model. By the designers issuing the model at an early stage, the supply chain can look to further analyze the design presented and input their own ideas on build ability or product selection (Eastman et al., 2011). This method of interaction was previously difficult for engineer as designs were generally set, whereas through BIM the design is open for all parties to review and discuss (Azhar, 2011).

This results in dramatic reduction in losses of information and decreases errors made by both design team members and construction team by offering the use of conflict detection. The clash detection item actually informs team members about parts of the building in conflict or clashing through detailed computer visualization of each part in relation to the whole building (Azhar, 2011).

BIM produces construction documents that comprise information about structure, quantities, materials and other data that can be used in both the construction and management of a building. It can be used to visualize the building and development site with realistic, real-time design settings to show how it will look like at any point in time. Once the model is taken to the construction phase of the project, the contractor commences working on site with a set of drawings he understands, a program determining the methodology of the construction and a schedule of the materials he requires to construct the works. In fact, it gives contractor a real perspective view of construction items on a hand-held computer which affects rework reduction (Aranda-Mena et al., 2008) in comparison with a hard-copy plan in the traditional ways.

Another key competitive advantage of BIM is its ability to promote greater transparency and collaboration between suppliers and thereby reduce waste through all levels of the supply chain (Eastman et al., 2008). BIM will also provide the ability for contractors to abstract material quantities from the model. This enables the contractor to accurately measure and quantify the elements of the structure efficiently and with a greater degree of detail than previously available. The provision of detailed quantity schedules for materials enables contractors to remove risk from their pricing models and ensure that clients are being provided with quotations that are based on precise data and data that should be consistent across all the parties tendering for a contract.

Although BIM may solves or diminishes some of the problems such as the extent of change orders made by the owners, its adoption has been less than expected (Azhar et al., 2008). It is likely that it causes some other issues which breads costly effects.

4.3 Lean Construction:

Lean Construction (LC) embodies a philosophy of production management that is often contrasted to mass production and craft production (Koskela, 1992; Ballard and Howell, 1998; Howell and Ballard, 1998). Lean construction is a design and execution methodology to minimize all types of waste applicable in construction and generate the maximum value in the construction processes. According to Eriksson (2010) LC have six core elements including: waste reduction, process focus in production planning and control, end user focus, continuous improvements, cooperative relationships, system perspective. Waste in this respect is defined as (Womack and Jones, 1996):

"Any activity which absorbs resources but creates no value"

Waste is basically classified as: (Womack and Jones, 1996; Liker, 2004):

1. Defects;
2. Overproduction;
3. Excess inventories;
4. Over processing;
5. Excess motion;
6. Redundant transportation; and
7. Waiting

This classification also has been widely accepted in construction (Mossman, 2009) and described as:

• *Defects/Reworks*. Scrap or re-doing works that adds costs with no increase in value. For instance, rework of drawings and paper work, mistaken installation, relocating of extra materials after installation, the re-scheduling of meetings when required people. This can be due to out of sequence work, unclear or late information, late decision making, inaccurate drawings and poor quality materials.

• *Overproduction*. The building or producing more than what is needed or producing too early which could lead to one or more of the other wastes. This can be seen in reports and presentations containing more information than needed or produce too frequently and use wrong details. This happens because of overdesign due to undefined requirements from the end user, just-in-case logic that leads to design more than needed or fabricating material too early.

• *Transportation*. The moving material from one place to another. This waste can be seen in excessive and multiple moves of materials. It can happen due to lack of process flow, poor site layout, lack of planning and early deliveries adding to the congestion to the site.

• *Waiting*. The delay or idle time before a person is able to start the next activity. This is seen by the waiting for approvals, waiting for the late timesheets, waiting for instructions or materials. This may occur due to late decision making, inadequate coordination and the delays creating because of drawings.

• *Over processing*. The performing more operations or using excessive specifications yielding no additional value. This can be seen in redundant reporting, several handling of timesheets, lack of clarity with paper work, excess of coordination required between suppliers. This may happens due to lack of communication, mistrust resulting in more inspections than quality checks.

• *Motion*. The extra body movements and searches that do not produce any additional value to the job. This can be seen by the excessive searching for information, the walking from meeting to meeting and poor work area layouts resulting in disastrous injuries and safety issues. This occurs due to poorly design processes, lack of standard work methods, no pre-planning and poor work area organization.

• *Inventory*. The work stocked up too far in advance when needed or in big batches waiting for use. This may trigger other wastes such as unnecessary transports or defects from mishandling or corruption. This can be seen by document such as waiting approval. This happens due to mistrust and lack of resource planning and may result in other wastes such as having to move materials around or replacement of dirty materials.

Lean Construction planning and control techniques reduce all above-mentioned types of waste by improving workflow reliability. The starting point is improving the reliability of tasks at the participant team level. This is in contrast to current management approaches that rely on project level plans to manage contracts instead of managing work, and contract commodity-based control systems that do not measure planning systems performance (Howell and Koskela, 2000).

Lean Construction starts by stabilizing the workflow through reliable planning, which shields the labor from that uncertainty management cannot control. Bringing in certainty into the flow of work improves performance of the immediate production. Predictable flow at any point in the supply and assembly chain then makes it possible to reduce inflow variation upstream and redesign operations downstream (Howell and Ballard, 1998).

In the conventional way of performing construction projects, several problems are caused due to the problem related to the flows among value-creating work steps (Salem et al., 2006). However, under LC, the "flow" based approach aims to accomplish Just-In-Time (JIT), by removing the variation caused by work scheduling (Howell and Koskela, 2000) and thereby provide a rationale or target and priorities for implementation, using a variety of techniques. The effort to achieve JIT disclosures many quality problems that are hidden by buffer stocks (Bertelsen, 2004); by forcing smooth flow of only value-adding steps, these problems become visible and must be dealt with explicitly.

Therefore, LC extends from the objectives of a lean production system - maximize value and minimize waste. As a result:

- The facility and its delivery process are designed together to better reveal and support customer purposes.
- Work is structured throughout the process to maximize value and to reduce waste at the project delivery level (Howell and Ballard, 1998).
- Efforts to manage and improve performance are aimed at improving total project performance.
- The performance of the planning and control systems is measured and improved.

- The reliable release of work between specialists in design, supply and assembly assures delivery of value to the customer and reduction of waste.

According to Salem et al. (2006), LC concentrates on defect prevention. It is also emphasized by several researchers that lean thinking plays an important role in quality aspects by generating *defect-free* products in the shortest possible time with the least amount of resources (Womack et al. 1990; Koskela 1992; Ballard and Howell 1997).

Despite the discussed benefits of LC, the application of lean in construction is still rather limited and incomplete (Matthews et al., 2000) as it is "still in its early adopters phase" (Miller et al., 2009). A numbers of challenges regarding its wide adoption can be found in the current literature. For example, Sarhan and Fox (2013) identified three major obstacles of successful implementation of LC as: (1) lack of enough awareness and understanding about lean, (2) absence of top management commitment; and (3) cultural issues. What these arguments indicate is that there should be more attentions and investigations regarding "lean" widely adaptation and implementation in construction.

5 Evidences of Poor Quality Costs in BIM and Lean Literature

In this section, it is tried to review the literature giving the promises about poor quality related costs in BIM and Lean literature.

5.1 Poor Quality Costs in BIM literatures

There are large amounts of literature on BIM as an emerging research topic. Different promises in favor of BIM are discovered in this review. Some of them are so broad and include several promises such as the followings:

> "Many projects have now successfully implemented BIM, demonstrating significant benefits: increased design quality, improved field productivity, cost predictability, reduced conflicts and changes, less rework, increased prefabrication, and reduced construction cost and duration. This results in a faster and more cost-effective project delivery process, and higher quality buildings that perform at reduced costs" (Hardin 2009; Eastman et al. 2008 cited in Building information modeling (BIM) 'best practice' project report, 2011).

> "Owners perceived the greatest savings in terms of time and money as a result of clash detection, rework avoidance, lower overall project costs, better project outcomes, improved process outcomes and better-performing buildings" (McGraw-Hill Construction 2009, p. 34).

Some other promises are even narrower and focus on one or two benefits. Bryde et al., (2013) specifically promises about the extent BIM will decrease the rework cost associated with computer and software issues which was part of traditional way of undertaking construction projects:

> "…some of these extra costs, such as CAD rework, training or computer upgrades, are costs that can be reduced or eliminated by implementing BIM from the beginning of projects".

Sebastian (2011) promises about the potential of clash detection of BIM in reducing cost of re-design:

> "Reducing redesign/remake costs through clash detection during the design process".

Dehlin and Olofsson (2008) and Eastman et al. (2008; p. 422) cited in Sacks et al., (2010) not only promise about the potential of BIM in reducing re-design but also promise about its impact on the construction field:

> "Building modeling imposes a rigor on designers in that flaws or incompletely detailed parts are easily observed or caught in clash checking or other automated checking. This improves design quality, preventing designers from "making do" (Koskela, 2004) and reducing rework in the field as a result of incomplete design".

Eastman et al., (2008; p. 317) promises about reducing rework cost as a component of total construction cost reduction:

"BIM reduces the direct engineering cost in three ways:

- Through the increased use of automated design and analysis software
- Almost fully automated production of drawings and material takeoffs
- Reduced rework due to enhanced quality control and design coordination".

Azhar (2011) went one step further. He used four case studies to discuss the benefits of BIM. According to Azhar the cost benefits of BIM implementation, which attributed to elimination of clashes was about $200,000 in Aquarium Hilton Garden Inn in Atlanta. In the design development stage 55 clashes were identified which resulted in a cost avoidance of $124,500. In the construction development stage 590 numbers of clashes were detected based on the estimates for making design changes or field modifications, which had not been detected earlier. The overall cost saving of this stage for the whole project was estimated about $801,565. However, it is not mentioned what types of cost elements are included in this cost and how the cost information are collected and subsequently calculated. Put in other words, Azhar, (2011) did not provide information about their cost collection, methods, definitions and aims as well as bases of comparison. It might be because the aim of these types of numbers and figures is to attract the attention of users about the cost benefits of BIM instead of providing further detail information on how these numbers are achieved. So, they cannot be considered as benchmarking metrics or bases for making comparison with other data gained from previous studies.

Suermann and Issa (2007) by using a survey instrument asked National BIM Standard (NBIMS) committee members' perceptions about BIM impacts on the six construction Key Performance Indicators (KPIs). The highest ranking KPIs were quality control and rework.

In American Institute of Architects (AIA Web Site 2005, cited in Aranda-Mena et al. 2008), one promise about the benefits of BIM in comparison with the conventional paper based documentations is found:

> "BIM is much more than 3D rendering or transferring electronic versions of paper documents. By implementing BIM risk is reduced, design intent is maintained, quality control is streamlined, communication is clearer, and higher analytic tools are more accessible".

McGraw-Hill Construction (2009; p. 22) cited in Giel and Issa, (2013) promises about the benefit of BIM on the amount of return on investment (ROI) through reducing conflicts:

> "The multiple benefits of BIM potentially affect its estimated ROI and it was determined that 68% of users recognize that reducing conflicts produces the highest rewards on a project".

It is surprising that most of the researchers have promised about the design and cost benefits of BIM among the other benefits.

5.2 Poor Quality Costs in Lean literatures

It is found that several papers indicate the importance of lean construction in increasing quality or also reducing poor quality costs (Aziz and Hafez, 2013; Al-Aomar, 2012). The "promises" such as:

> "Improving quality in the construction context contributes to the lean focus on speed delivery and cost effectiveness by reducing reruns, delays, and re-works in the completed tasks…" (Al-Aomar, 2012)

is found in the current literature.

Wills (2009) cited in Nahmens1and Ikuma (2012) promise about the benefit of lean to reduce all types of waste including poor quality cost such as cost for rework:

> "Traditional lean theories purport lean to be a method for improving the economic bottom line through improved efficiency and reduction of all types of waste, whether the waste is from excess materials, labor, time, or other sources".

The same promise is also given by Koskela (1999):

> "The basic improvement rationale in lean production is to compress the cycle time by eliminating non-value-adding time. The cycle time refers to the time required for a particular piece of material to traverse the flow…Cycle time compression forces the reduction of inspection, move and wait time. In other terms, the basic thrust is to eliminate waste from flow processes. Thus, such practices as elimination of inventories, reduction of rework, short distances between work stations, etc. are promoted. In fact, this is the rationale of JIT production".

Al-Aomar (2012) promises about its benefits for construction companies:

> "The work of construction companies largely contributes to the quality and safety of public and society at large through residential and commercial buildings, transportation, and infrastructure projects. Lean construction practices and Six Sigma rating positively impact these important aspects and often result in reducing waste and costs, improving safety, and saving energy resources in construction projects".

Fearne and Fowler, (2006) went much deeper and promise about the positive influence of lean on poor quality problems where it is mentioned that:

> "The rationale behind "going lean" centers on waste removal both inside and between companies. Waste removal is fundamental to a lean value stream. The

> reason for this is that improved productivity leads to leaner operations, which help to expose further waste and quality problems in the system. The systematic attack on waste is also a systematic assault on the factors underlying poor quality and fundamental management problems".

Even though such promises have been presented in the reviewed literature, none of them are currently followed up and validated by first-hand evidences.

6 Discussion and Concluding Remarks

There are a growing number of researches about BIM and LC in recent years. The literatures discuss and address different trends and issues concerning these two tools. Today, many construction organizations, managers and investors have a “wait-to-see” attitude about the benefits of these tools. One of the ways, which can prove the benefits of these tools, is measuring quality cost or poor quality cost.

However, this review highlights several significant gaps in knowledge about the evidences concerning promises in favor of implementing BIM and LC. Just one study among reviewed papers about BIM presented some overall evidences. None of the studies followed up the benefits of LC.

In terms of BIM studies, just one study went one step further and provides some overall figures and numbers. But, the results are not so much satisfactorily and leave the readers in the dark about the employed definitional and methodological aspects. These points indicate poverty of attention and consciousness about following up poor quality costs among the researchers studying BIM and LC literature. It also reflects the immaturity of these research areas, which needs further investigations.

Paying attention to poor quality cost in BIM and LC related projects can bring a lot of benefits. Firstly, construction managers and investors will be encouraged to invest on these tools. Secondly, it provides the possibility of benchmarking, measuring the performance, revealing the weakness areas, etc. which provide a baseline for further improvement actions and trying to enhance the level of BIM and LC performance. In other words, measuring poor quality costs such as costs incurred due to rework helps construction professionals and managers to have a better insight about the size of poor quality cost after BIM and LC implementation so they can eliminate or at least reduce further causes of poor quality. Hence rectify some of the BIM and LC obstacles for widest implementation of them. Also, its measurement can be considered as a type of waste measurement which is useful to support process management and provide the opportunity for operational costs modeling and create meaningful information for the employees (Aziz and Hafez, 2013). However, some of the other challenges regarding BIM and LC still may remain hidden and need other types of management tools and approaches.

Researchers should be well aware of the fact that providing more detail information about the methods of data collection, terms and definitions, makes it possible for the users and other practitioners to have a better insight about reported results and assess if the results are reliable. Moreover, it enables them to make a reasonable comparison between the results of different investigations and use for benchmarking actions.

Future research

In order to prove the benefits of BIM and LC in favor of poor quality costs reduction, the present author suggests further studies and case studies can be conducted to measure the cost associated with poor quality activities in construction projects implementing BIM and LC. This helps construction managers and owners to feel confident about quality improvement and cost trends through BIM and LC implementation. Moreover, it enables them for identifying and highlighting further likely areas of concern which need further attention.

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