Evaluation and modelling of the costs of non-quality in the Portuguese construction industry

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This paper is the extended abstract of a MSc dissertation with the same title. The work addresses the subject of quality related costs as an instrument for the reduction of the costs of doing business in the construction industry. This cost reduction would eventually improve the competitiveness of companies in a very competitive industry. A comprehensive literature review was carried out in order to get a thorough understanding of the researches conducted on this topic. Since there is no published research on this topic in Portugal, a questionnaire was developed and sent to Portuguese construction companies to obtain preliminary data on the subject. Although few companies responded to the survey, there is evidence that points to significant quality related costs, in particular costs of non-quality.

Keywords: quality, non-quality, costs, construction.

1. Introduction

The construction industry is becoming more and more competitive, with companies having lower margins of profit. This industry is also characterized by the individual nature of each construction work, a high proportion of temporary unskilled workers and a slow penetration of new technologies. The combination of these factors is responsible for a great incidence of errors in the construction processes, which implies more costs and, consequently, the reduction of the profit margins.

One solution to raise the profit of construction companies is therefore the reduction of these errors through the implementation of quality management activities. Errors originate defects or failures whose costs are known as costs of non-quality, while the costs of the quality management activities are known as costs of quality. The sum of these costs is called quality related costs or as total quality costs.

The evaluation of quality related costs is a management tool widely used in the manufacturing industry. The main advantages associated with the knowledge of these costs are:

- Recognition of the magnitude of non-quality;
- Identification of the quality management activities most effective for the reduction of the total amount of these costs;
- Comparison of these costs between the various projects undertaken by a company or comparison of these costs between companies.

The Prevention, Appraisal and Failure (PAF) model is widely accepted for the categorisation of quality related costs. This model divides the costs of quality in prevention and appraisal costs and the costs of non-quality in internal and external failure costs. Prevention costs are those incurred with activities performed to prevent or reduce errors. The costs of evaluating the achievement of the established or implicit product requirements are the appraisal costs. Finally, the internal and external failure costs are the costs associated with failures detected, respectively, before and after the handover of the finished construction to the client.

In this paper a revision of the literature concerning the evaluation of the quality related costs in the construction industry is presented, followed by the results of a survey conducted as an attempt to acquire some knowledge on the issue of quality related costs in the Portuguese construction industry.

2. State of the art

Identification and collection of quality related costs

The need for systems that identify and collect the quality related costs comes from the inability of the conventional accounting practices to identify those costs among all the costs of a company. The main characteristics of those systems should be ease of use, to minimize extra costs and facilitate cooperation by the staff, and flexibility, to adjust the system to different needs.

Implementing this kind of systems in the construction industry hasn't been easy. In part this is a consequence of the fact that senior management is not convinced of their utility. However other reasons have been identified, namely the additional work brought to a sector that is characterized by a heavy workload and the threat felt by the staff regarding the evaluation of their work implied by these systems.

Since the 1980's several systems have been developed to quantify the quality related costs and to identify the causes of quality failures in the construction industry. Most of these systems focus only on the construction phase of a project, neglecting the design phase. One of the first was the Quality Performance Management System (QPMS), developed at the Construction Industry Institute (CII, 1989). QPMS was based on activity-based costing, defining 8 types of quality management activities and 7 causes of failure.

The Quality Performance Tracking System (QPTS), also developed at the CII (Davis *et al*., 1989), is an upgrade of the QPMS. This system classifies the quality related costs in costs of quality management efforts and costs of correcting deviations. Deviations being the main issue of QPTS, it intends to address several questions concerning deviations. According to Love and Irani (2003) this system was the first to consider the cost of repeated prevention or appraisal activities due to a failure as a cost of non-quality instead as a cost of quality.

Later, arguing that a simple method for quantifying the costs of non-conformity did not exist, Abdul-Rahman (1993) developed the Quality Cost Matrix (QCM), a matrix with the aim to quantify those costs in construction sites.

In the late 1990s, Low and Yeo (1998) developed the Construction Quality Cost Quantifying System (CQCQS). Its main characteristic is the use of codes to classify the quality related costs. The origin of the failures is not addressed by the CQCQS.

The main innovation of the Project Management Quality Cost System (PROMQACS), designed by Love and Irani (2003), is the centralisation of the data about the failures from all parties involved in the construction project. Therefore the evaluation of the costs of failures is more comprehensive and rigorous. This system was developed in partnership with an Australian contractor.

The systems presented until now are based on the PAF model. Differently, the system presented by Aoieong *et al*. (2002) is based on the process cost model. It aims to quantify the cost of specific processes, dividing them in costs of conformity and costs of non-conformity. According to the authors the process cost model is simpler and requires fewer resources than the PAF model.

Costs of quality costs vs. costs of non-quality

In the last decade several researches have been conducted with the objective of quantifying both types of quality related costs in the construction industry. Besides that, Kazaz *et al*. (2005) and Rosenfeld (2009) attempted to identify the minimum value of the total quality related costs, which matches the optimum investment in quality. The existence of this minimum value is related to the inverse relationship that exists between the costs of quality and the costs of non-quality, as stated in Figure 1.

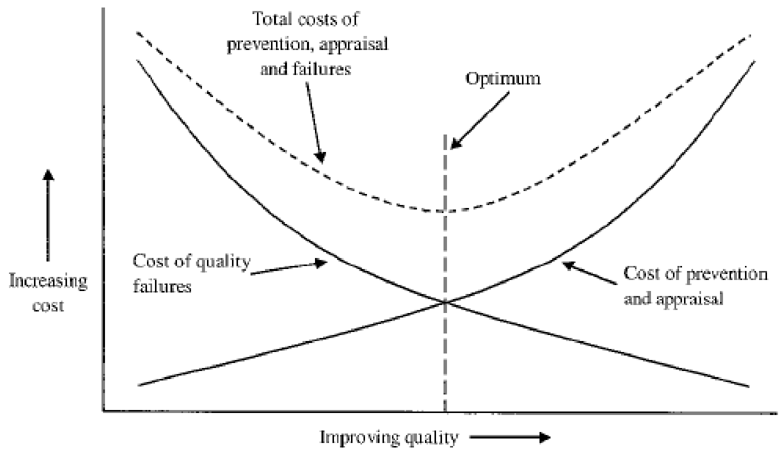

Figure 1 - Classic relationship between the quality related costs and the quality level (Foster, 1996)

The position of the minimum of the total quality related costs curve varies according to the nature of the projects, while never matching the quality level that represents 0% of defects or 100% of conformity to the requirements (Kazaz *et al*., 2005).

Hall and Tomkins (2001) sought to quantify the total quality related costs in the construction of an office development of low technical complexity in southern England. The site staff was responsible for recording the failures detected during construction in “log sheets”.

The total cost of quality failures was 5,84% of the contract sum while prevention and appraisal activities accounted for 12,68%. The cost of failures were almost entirely the cost of resources (labour, materials and plant) used in their correction. The largest portion of the cost of failures was caused by “suppliers”, being responsible for 55,03% of these costs. This category also includes the failures attributed to subcontractors. Prevention and appraisal costs were obtained by the review of document sources, specially the bill of quantities.

The research team evaluated the cost of the delays arising from failures in activities in the project critical path. This exercise showed that delays cost 1,11% of the project cost. Since delays are a subset of quality failures, the direct cost of failures was 4,73% of the contract sum.

The purpose of Kazaz *et al*. (2005) was to quantify the total quality related costs in a mass-housing project in Turkey. This project totalled 3100 housing units, including buildings with 5 or more storeys, buildings with 3 or 4 storeys and two-storey buildings.

For the three types of buildings the costs of quality were higher than the costs of failures. The costs of failures averaged 11,53% of the total cost to the client while the costs of quality were, on average, 20,83% of the same value. The information concerning prevention and appraisal activities was obtained mainly from the construction company's records. The data used in the quantification of the internal failures cost was collected on site while the external failures cost was calculated by means of a survey to 655 householders of the 3 types of buildings. For both the internal failures and the external failures only costs of rework were considered.

Both the costs of quality and the costs of non-quality were fitted with polynomials in order to determine the minimum of the total quality costs to the 3 types of buildings. It was concluded that the minimum total quality cost is 16,75% of the total cost to client in high-rise buildings, 24,96% in medium rise buildings and 24,75% in two-storey buildings.

The research conducted by Rosenfeld (2009) was an attempt to determine the optimal level of investment in quality by construction companies. For this purpose the four types of quality related costs defined in the PAF model were quantified for eight Israeli building companies. A scatter diagram was used to plot the costs of quality versus the costs of non-quality for each company. Using the equation of the statistical regression performed in the scatter diagram, a function was created to model the total quality related costs depending on the expenditure in quality. The minimum value of this function was 4,05%, corresponding to a cost of quality of 1,8% of the company's revenue. Rosenfeld (2009) also attempted to estimate the hidden, intangible and indirect costs of non-quality. However it was a crude estimation, resulting in unreliable values for the quality related costs.

Following the work carried out by Aoieong *et al*. (2002), Tang *et al*. (2004) captured the quality related costs using the process cost model (PCM) in the concreting process of two construction projects in Hong Kong: the concreting of 18 typical floors of two residential blocks (case study 1) and the concreting of 30 pile caps of a single two-lane carriageway (in case study 2). In this research the cost of conformance (COC) was the cost of providing the concrete products according to the established requirements. This cost was composed by the costs of labour, materials and equipments. The cost of non-conformance (CONC) was based on the time and labour required to correct each non-conformance and on the materials and resources wasted. The cost of the concreting process in case study 1 was comprised on average by 99,48% of COC and 0,52% of CONC. In case study 2, the cost of the concreting process of the pile caps were made on average of 99,75% of COC and 0,25% of CONC.

Costs of non-quality

Many research works focus only on the cost of non-quality, which is also the main focus of this dissertation. Different designations are given to the failure to comply with the established requirements, i.e., to non-quality. The following terms are used: deviation, defect, failure, non-conformity and rework. As stated by Rosenfeld (2009), this diversity of designations is a sign that the research on this topic needs maturation.

Burati *et al*. (1992) studied 9 industrial construction projects in the USA in order to quantify the costs and the causes of the quality deviations. The deviations were classified in five areas according to their origin, and by type as change, error or omission. On average, the design deviations were 78,3% of the total number of deviations observed in the nine industrial projects. This value is composed by 52,5% of changes, 19,7% of errors and 6,1% of omissions.

The total deviation costs ranged from 0,4 to 25,9% of the total installed project costs. The average value was 12,4%, with 9,4% due to design related deviations and 2,5% to construction related deviations. The remaining 0,4% are distributed by the other three areas of origin, i.e., fabrication, transportation and operability. The financial consequences considered included only the costs of direct rework.

Abdul-Rahman used the QCM to evaluate the cost of correcting non-conformities in the construction phase of two construction projects. The first one (Abdul-Rahman, 1995) was the construction of a highway and the second one the construction of a water treatment plant (Abdul-Rahman *et al*., 1996). Staff members were responsible of recording the non-conformities in the matrix and classify them in one of the established categories. The list of categories was not the same in both works.

In the research conducted by Abdul-Rahman (1995) the cost of correction of the non-conformities was 5% of the tender value of the project. The category “Subcontractor and supplier” was responsible for 48,2% of the total non-conformity costs and the “Construction-related” category for 21,0% of those costs. On the other hand, Abdul-Rahman *et al*. (1996) estimated that the total cost of the non-conformities was 6% of the estimated project cost, assuming that these costs emerged at a constant rate, since the observations didn’t cover the entirety of the construction phase. More than three quarters of these costs went to the following categories: “Subcontractor” (with 40,10% of the total non-conformity costs), “Co-ordination and planning” (with 16,30%), “Construction-related” (13,00%) and “Setting-out” (7,03%).

Josephson and Hammarlund (1999) cooperated with the Chalmers University of Technology (Gothenburg, Sweden) to unveil the origin and causes of the defects occurred in seven construction projects. An observer in charge of recording the defects which arose was assigned to each of the construction sites. On average 50% of the costs associated with the defects was caused by the lack of motivation, expressed in forgetfulness or carelessness. Lack of knowledge was the cause for 29% of the defect costs. Almost half of the costs with the defects (45% on average) originated at the construction site. The early stages of the projects, related to the client and to design, were also responsible for a large proportion of the costs, accounting for an average of 32% of their total. In the seven construction projects, the cost of the defects detected ranged between 2,3% and 9,4% of the production cost of the project, with an average of 4,9%.

Two construction projects were examined by Barber *et al*. (2000) with the intent of quantifying the costs of quality failures. One project, Scheme 1, was the construction of several kilometres of a new road. The other project, Scheme 2, consisted of the construction of many kilometres of a highway. The key persons of both projects were shadowed by observers and the quality failures found were recorded. Every failure was then classified in one of the following cost categories: "< £500", "£501-£1.000", "£1.001-£5.000", "£5.001-£10.000" and ">£10.000".

In Scheme 1, the failures detected cost 6,6% of the budgeted cost of the project, while in Scheme 2 the failures cost 3,6% of the same value. Including an estimation of the cost of delays caused by failures, the failure costs ascend to 15,76% of the budgeted cost of the project in Scheme 1 and to 23% in Scheme 2.

In both projects the cost category ">£10.000" holds only 4% of the failures, however these failures represent 68% of the total failure costs in Scheme 1 and 44% in Scheme 2. The cost category "< £500" comprises 59% of the failures in Scheme 1 and 82% in Scheme 2, but that corresponds only to 9% of the total failure costs in Scheme 1 and 10% in Scheme 2.

Love and Li (2000) studied the incidence of rework in two Australian construction projects (Projects A and B). Project A consisted of two residential blocks with 6 floors, while Project B was an industrial warehouse with 2 floors. The contractor was the same for both projects. Each construction site was visited in order to record the rework incidents.

In Project A, 72% of rework costs are design related and 28% are construction related. For Project B, the costs of rework related to construction were higher than those related to design, being 80% and 20%, respectively. The design changes (responsible for 53,70% of total rework costs) and the changes during the construction (with 21,40%) were the main causes for rework in Project A. On the other hand, in Project B the major causes for rework were the changes and errors during the construction phase, accounting for 50% of the total costs of rework. This research revealed that rework costs were 3,15% and 2,40% of the contract value for Project A and Project B, respectively. These figures reflect only the direct costs of rework.

A large scale study was undertaken by Love and Edwards (2005) with the aim of estimating the total rework cost (direct and indirect cost) in the Australian construction industry. This objective was pursued conducting a questionnaire to construction practitioners throughout Australia. Respondents were asked to select a project they were involved in and answer the questions based on it.

The estimates for the rework costs given by the respondents varied widely, ranging from under 1% to about 80% of the contract value. This variation may be a sign that practitioners are not sure about the real cost of rework. The mean value of the rework costs of the 161 projects was 12% of the contract value, which is a sum of 6,4% of direct costs and 5,6% of indirect costs. Relying on the answers to a question asking if the estimate made for the rework costs of the project was comparable to other projects where the respondents have been involved it can be concluded that the estimates presented before are generally representative of the whole Australian construction industry.

3. Questionnaire

Structure of the questionnaire

A questionnaire was developed in order to obtain data concerning costs of quality and costs of non-quality in Portuguese construction companies. It was sent via e-mail to 180 of the first 200 companies[1] in the ranking of the 500 largest Portuguese construction companies. Whenever possible the questionnaire was e-mailed directly to the quality department of the company.

The questionnaire was structured if four parts. The first part was intended to characterise the companies in terms of financial data, number of employees and type of construction works they perform. The second part included general questions concerning quality management issues. The third and fourth parts of the questionnaire were intended to collect quantitative data on quality and non-quality costs. Several types of cost were considered according to the PAF model, as shown in Table 1.

Table 1 - Types of quality related costs considered in parts 3 and 4 of the questionnaire

Costs of quality	
Prevention costs	**Appraisal costs**
Costs of quality department staff Costs of training on quality-related issues Cost of internal quality audits Cost of accreditation and monitoring of suppliers	Cost of controlling materials and products Cost of internal controlling during construction Cost of equipment for quality control Cost of inspections before delivery
Costs of non-quality	
Internal failure costs	**External failure costs**
Cost of correcting design documents developed in the company Cost due to deficiencies in tenders Cost resulting from deficiencies in planning Cost resulting from failures in the supply system Cost resulting from breakdown of equipment	Cost of handling customer complaints Cost of repairs during warranty Cost of compensations, fines and other legal costs

For each type of cost the respondents were requested to select one of four possible cost intervals: "< 0,5%", "0,5 - 1%", "1 – 2%" and "> 2%" of the total annual costs. In addition, it was asked if the quantification was based on company records or if it was just an estimate. It was also possible to recognise the existence of a given type of cost even if its quantification was not possible.

Analysis of the answers

The delivery of the questionnaire was unsuccessful for 18 of the 180 companies. Two other companies stated that they are not active in the building or civil engineering sector. Thus, it may be assumed that 160 companies received the questionnaire. Only 9 companies answered, which corresponds to a response rate of 5,6%. This low response rate hinders a statistical analysis of the answers and consequently the conclusions presented are essentially qualitative and must be taken

[1] The remaining 20 companies could not be included in the survey due to different technical reasons.

with caution. The 9 responding companies are denoted by letters, from A to I, in descending order of the ranking mentioned in the previous section.

All companies are certified by the ISO 9001 standard. Additionally, all of them also reported to have a quality department. These two evidences show that quality is definitely an unavoidable topic in the construction industry.

In the second part of the questionnaire, when asked if they keep individual records of quality related costs, the number of companies answering positively was greater for non-quality costs (5) than for quality costs (3).

Analysing the main reason indicated by the companies to not individually record the costs of quality and the costs of non-quality, it can be found that while 2 companies said that the recording of the costs of quality doesn't benefit them, none appointed that reason for not individually recording the costs of non-quality. This observation and the one made previously seem to show that construction companies see the knowledge of the costs of non-quality as more important than the knowledge of the costs of quality. Other reasons presented by the companies to not perform the individual recording of the quality related costs are the high complexity associated to this recording process, the satisfaction with current accounting practices and the insufficiency of resources. The difficulty inherent to the quantification of the quality related costs was also addressed by Aoieong *et al*. (2002). This issue was referred by some elements of construction companies of Hong Kong when interviewed by the authors.

Using data collected in parts 3 and 4 of the questionnaire for the types of quality related costs listed in Table 1, it was possible to estimate the costs of quality and the costs of non-quality incurred by the responding companies. Since the costs were quantified by means of intervals, their total value is also presented as an interval. In Figure 2 the costs of quality and the costs of non-quality of the 9 companies are presented.

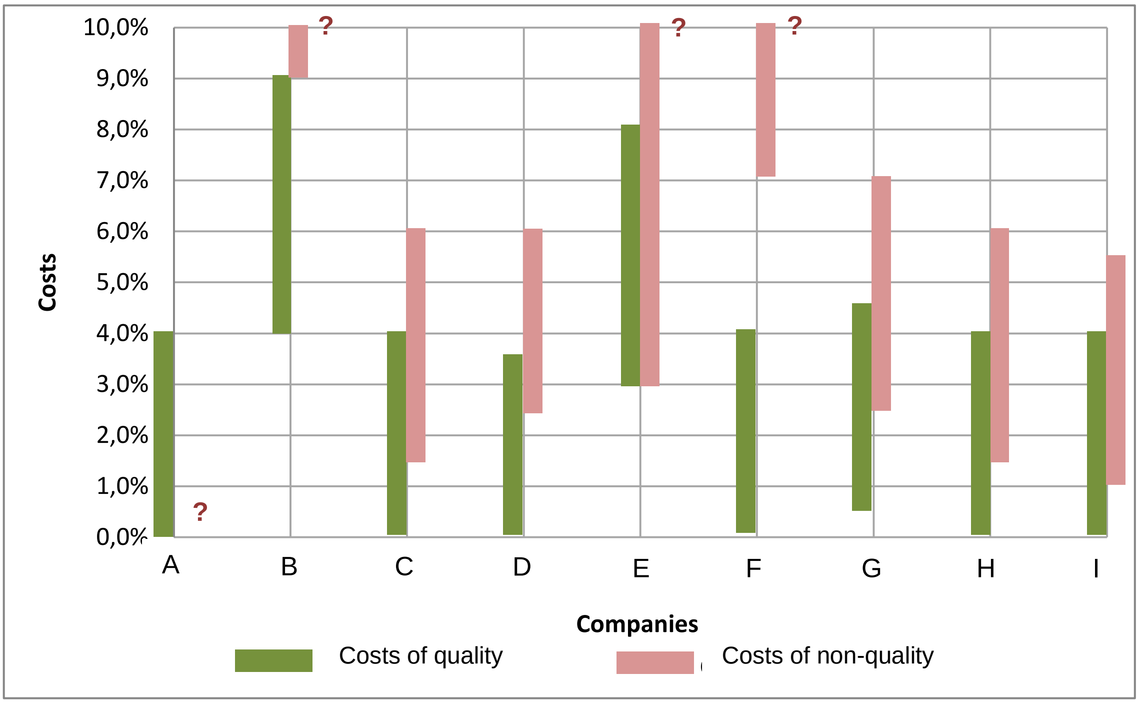

Figure 2 - Costs of quality and costs of non-quality of the 9 companies

The costs of non-quality of some companies are shown as open intervals (represented by a question mark near the top of the bar). This happens because one of the quantification intervals defined in the questionnaire was right opened (> 2%) and also because respondents were allowed to recognize the existence of a given type of cost without providing the corresponding value or estimate.

From the available data it is impossible to conclude precisely which group of quality related costs has higher values. The examination of Figure 2 shows that only the costs of companies B and F are represented by disjoint intervals. For these two companies the costs of non-quality are higher than the costs of quality. Nevertheless, this same behaviour seems to be the trend in the remaining companies. This trend is compatible with the results of one of the three researches presented in this paper that assessed both groups of quality related costs, but not with the findings of the other two.

Although company B had the highest cost of quality, it was also the company with the highest cost of non-quality. This behaviour is somewhat surprising since it is expected that higher investment in quality should reduce the costs of non-quality[2].

The existence of the 17 types of quality related costs listed in the questionnaire is generally confirmed by all the companies. From the 9 companies that answered the questionnaire, only company D did not recognize the existence of all types of cost. Despite this fact, the percentage of quality related types of cost that is recorded by the companies is low. Only about one third of the types of cost recognized by the companies are individually registered in their accounting records.

Excluding companies A, B and F, the lower limit of the costs of non-quality lies between 1 and 3% of the total costs of the companies and the upper limit between 5 and 7%. For the upper limit, company E was also excluded because it wasn't possible to determine that limit, as can be confirmed in Figure 2. With these exclusions we can say that the cost of non-quality ranges between 1 and 7% of the total costs of the companies. Comparing with the costs of non-quality mentioned in the studies concerning only this group of costs, presented previously, a reasonable compatibility is noticed with the costs found in the present research. Those costs are summarised in Table 2 with the exception of the costs of non-quality calculated in Barber *et al*. (2000) that included an estimate for the costs of delay. Nevertheless, as can be seen in Table 2, the costs of non-quality in the different works are shown as percentages of different values, making difficult their direct comparison.

Table 2 - Cost of non-quality observed in another researches

Research	**Value**	
Love and Li (2000)	2,4%	of the contract value for Project B
Love and Li (2000)	3,2%	of the contract value for Project A
Barber *et al*. (2000)	3,6%	of the budgeted cost of the Scheme 2
Joseph and Hammarlund (1999)	4,9%	of the production cost
Abdul-Rahman (1995)	5,0%	of the tender value of the project
Abdul-Rahman *et al*. (1996)	6,0%	of the estimated project cost
Barber *et al*. (2000)	6,6%	of the budgeted cost of the Scheme 1
Love and Edwards (2005)	12,0%	of the contract value
Burati *et al*. (1992)	12,4%	of the total installed project costs

[2] A possible explanation could be the way this particular company quantifies or estimates quality related costs.

Based on the definition of micro, small and medium companies established in the Portuguese decree-law nº 372/2007, of November 6th, the companies A, B and C are seen as large companies while the remaining are considered of small and medium size. The results of the questionnaire don't suggest any relation between the company's size and its expenditure in quality or non-quality.

As stated previously, all the companies are certified by the ISO 9001 standard. However they were first certified in different years. The comparison of the quality related costs of each company with its ISO 9001 maturity doesn't show any correlation between these two variables.

4. Conclusions

The low response rate to the questionnaire limited the extent and the type of analysis of the answers. An essentially qualitative analysis of the answers was performed and the conclusions presented below must be viewed with caution.

Quality is a subject definitively present in the Portuguese construction industry. As previously stated, all the answering companies claimed to be certified in accordance to the ISO 9001 and to have a Quality Department in their structure. The ISO 9001 certification can be a sign that construction companies are more aware of quality issues but may also reflect the fact that certification is becoming a common requirement for the companies to be able to tender for public contracts.

Even though the answers suggest that the companies give more value to the knowledge of the costs of non-quality, the percentage of the types of cost quantified based on records was almost the same for both groups of costs, quality and non-quality. This preference for the knowledge of one of the two quality related costs seems to show that companies ignore the interrelation between costs of quality and costs of non-quality, as illustrated in Figure 1.

For most of the responding companies, the costs of non-quality appear to have a tendency to be greater than the costs of quality. The costs of non-quality of the majority of the companies that cooperated in this research lie between 1 and 7% of the total costs. This interval includes the costs of non-quality found in many studies on this subject.

No correlation was found between the size of the companies and the extent of their quality related costs, nor between the company's ISO 9001 maturity and their expenditure in quality related costs.

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References

Abdul-Rahman, H. (1993). Capturing the cost of quality failures in civil engineering. *International Journal of Quality & Reliability Management*, *10*(3), 20-32.

Abdul-Rahman, H. (1995). The cost of non-conformance during a highway project: a case study. *Construction Management and Economics*, *13*, 23-32.

Abdul-Rahman, H., Thompson, P.A. and Whyte, I.L. (1996). Capturing the cost of non-conformance on construction sites: An application of the quality cost matrix. *International Journal of Quality & Reliability Management, 13*(1), 48-60.

Aoieong, R.T., Tang, S.L. and Ahmed, S.M. (2002). A process approach in measuring quality costs of construction projects: model development. *Construction Management and Economics*, *20*, 179-192.

Barber, P., Graves, A., Hall, M., Sheath, D. and Tomkins, M. (2000). Quality Failure costs in civil engineering projects. *International Journal of Quality & Reliability Management*, *17*(4/5), 479-492.

Burati, J.L., Farrington, J.J. and Ledbetter, W.B. (1992). Causes of quality deviations in design and construction. *Journal of Construction Engineering and Management, ASCE*, *118*(1), 34-49.

CII (1989). Costs of Quality Deviations in Design and Construction. *Quality Management Task Force, Construction Industry Institute*, *10* (1).

Davis, K., Ledbetter, W. R. and Burati Jr., J. L. (1989). Measuring design and construction quality costs. *Journal of Construction Engineering and Management*, *115*(3), 385–400.

Foster Jr., S.T. (1996). An examination of the relationship between conformance and quality-related costs. *International Journal of Quality and Reliability Management, 13*(4), 50–63.

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

Josephson, P.-E. and Hammarlund, Y. (1999). The causes and costs of defects in construction, A study of seven building projects. *Automation in Construction*, *8*, 681-687.

Kazaz, Aynur, Birgonul, M. Talat and Ulubeyli, Serdar (2005). Cost-based analysis of quality in developing countries: a case study of building projects. *Building and Environment*, *40*(10), 1356-1365.

Love, P.E.D., and Li, H. (2000). Quantifying the causes and costs of rework in construction. *Construction Management and Economics*, *18*, 479-490.

Love, P.E.D. and Irani, Z. (2003). A project management quality cost information system for the construction industry. *Information & Management*, *40*, 649-661.

Love, P.E.D. and Edwards, D.J. (2004). Forensic project management: the underlying causes of rework in construction projects. *Civil Engineering and Environmental Systems*, *21*(3), 207-228.

Low, S.P. and Yeo, H.K.C. (1998). A construction quality cots quantifying system for the building industry. *International Journal of Quality & Reliability Management*, *15*(3), 329-349.

Rosenfeld, Y. (2009). Cost of quality versus cost of non-quality in construction: the crucial balance. *Construction Management and Economics*, *27*, 107-117.

Tang, S.L., Aoieong, R.T. and Ahmed, S.M. (2004). The use of Process Cost Model (PCM) for measuring quality costs of construction projects: model testing. *Construction Management and Economics*, *22*, 263-275.