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Cost of quality versus cost of non-quality in construction: the crucial balance

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The research is a pioneering attempt to determine the optimal level of investment in quality by construction companies. The methodology is based on quantifying the four types of quality-related costs in residential construction, and relates them to each other by expressing them all as percentages of the relevant total construction revenues (revenues to the company due to construction, excluding land, etc.). The findings reaffirm, on the one hand, that investing in quality is a worthy strategy and that, in the situations examined, the ratio of the direct benefits to the investment (in terms of savings on internal and external failures) is at least 2:1. On the other hand, the findings also show that an excess of quality costs (prevention and appraisal) is wasteful. Above a certain level of investment, the extra benefits are marginal, and thus do not offset the extra costs. Statistically fitted graphs, based on actual quantitative data, support this hypothesis, and provide approximate boundaries of effective versus ineffective investments in quality. In this study, the optimal range lies between 2% and 4% of the company's revenue. Investing less than 2% in prevention and appraisal will definitely entail higher failure costs, whereas an investment of over 4% most probably will not pay itself back.

Keywords: Quality, cost of quality, quality assurance.

Introduction

Construction projects are capital intensive and characterized by long, complex and interconnected processes of planning, design and execution. Myriad participants and business entities, orchestrated by project managers, carry out such projects. Since most construction projects are by nature one-of-a-kind prototypes, mistakes and rework are almost unavoidable. A quantitative analysis of the total quality-related costs (TQRC) incurred during the execution phase of construction projects was carried out for this study. The analysis emphasizes opportunities for saving a substantial part of the consequential costs of non-quality (CONQ) by sophisticatedly balancing them with investments in cost of quality (COQ), as an attempt to do it right the first time.

In recent decades, the entire industrialized world has witnessed a quality revolution (Feigenbaum, 1991; Hiam, 1992; Walton, 1992), which has gradually penetrated the construction arena as well (Griffith, 1990; Ashford, 1992; Burati and Oswald, 1993; Deffenbaugh, 1993). Customers demand, and eventually get, higher quality construction products, and they are more aware of the direct and the indirect costs of low quality. According to the ISO9000 principles, quality is a managerial issue and must be embedded in the production processes (Nee, 1996). Instead of focusing on negative measures, such as inspection and rejection at the end of the process, modern quality management approaches advocate proactive measures (Fazzi, 1994; Smith, 1996). Preference is given to *prevention* (e.g. proper training of personnel, and process analysis prior to the start of each job) and to *appraisal* during the process (e.g. routine monitoring and benchmarking using systematic checklists at various stages of the project). These measures are bound to minimize the incidence and severity of *interior failures* (discovered and corrected before transfer of the product to the customer) and *exterior failures* (discovered by the customer during use). The total quality-related costs, thus, include the above four components:

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the former two are considered costs of quality, i.e. the cost of measures taken to ensure and achieve a satisfactory level of quality, while the latter two are considered costs of non-quality, i.e. rework and other expenditures entailed by defective work.

This nomenclature was chosen by the author from a wide variety of definitions offered in the professional literature as the most appropriate for the analysis, which follows the simple logic that the more you invest in costs of quality, the less you can expect to waste on costs of non-quality.

The following sections present: (1) a short overview on quality-related costs in general, and in construction in particular; (2) the findings of this study's survey of eight construction firms; (3) analyses of the findings along with valuable insights; and (4) interesting conclusions with generalized lessons. The main contribution of this paper is in the new approach and practical methodology that it offers for quantitative evaluations of TQRC, allowing for cross-analyses of the relationships and dependencies among its variables.

Cost of quality and cost of non-quality

Quality-related costs in general

In their comprehensive critique, Plunkett and Dale (1988) summarized and classified most of the known-to-date models of economic costs of quality. In their work, they identified five major types of models, and analysed their strengths and weaknesses. They coined the concept of PAF (prevention—appraisal—failure), and brought to attention the observation that we can only control or dictate the allocation of resources for prevention and appraisal, while the failures appear only later, mainly as a consequence of the former. Campanella (1990) emphasized that consistent investment in prevention over several years brings about not only a reduction in the rate and cost of failures, but also savings in the cost of appraisal.

Burati *et al.* (1992) tried to quantify non-quality costs in nine US industrial projects by analysing deviations manifested by change-orders, rework, and so on. They found that these amounted to an average of 12.4% of the total project cost. Another US study by Ledbetter (1994) found that the sum of the COQ and CONQ for both design and construction stages amounted to 11.2% of the project cost. Willis and Willis (1996) also arrived at a similar figure of 12% TQRC (8.7% for prevention and appraisal plus 3.3% for failure costs) in a study performed on industrial construction engineering projects.

Burgess (1996) and Kamlesh and Peter (1998) compiled cross-industry comparative analyses of different components of quality-related costs, mainly as percentages of the firms' revenues. Their most conspicuous findings were that:

(1) Internal failures are the most expensive component of the total quality-related costs (in directly measurable monetary terms).
(2) Across all industries, the costs of non-quality were always higher than the costs of quality.
(3) Prevention costs were always the smallest component of the total quality-related costs.
(4) High failure costs were generally correlated with low prevention and appraisal costs.

Quality-related costs in construction

Several quantitative approaches have been applied in recent years to capture the cost of quality and cost of non-quality in construction. Abdul-Rahman *et al.* (1996) attempted to capture the cost of non-conformance on construction sites and found it to be 5%–6% of the total project cost. These results, however, were not analysed vis-à-vis prevention and appraisal costs. Low and Yeo (1998) developed a construction quality costs quantifying system based on a matrix approach that quantifies the various components of TQRC by category and subcategory. They also discussed the relationships among the four components of TQRC, and advocated augmenting prevention rather than appraisal. Aoieong *et al.* (2002), following previous studies, developed a holistic process approach for measuring quality costs in construction.

Several scholars focused on the waste part of TQRC: Swedish researchers Josephson and Hammarlund (1999) investigated seven building projects for the causes and costs of *defects* in construction. Love *et al.* (1999) and Love and Li (2000) focused on the causes and costs of *rework* in construction projects in Australia, while Barber *et al.* (2000) investigated the cost of *quality failure* in civil engineering projects in the UK. These three seemingly different terms—defects, rework and quality failure—are actually synonymous, and the lack of uniform keywords only indicates that this research area is still far from maturity.

All the abovementioned references indicate, on the one hand, that the construction industry is aware of the high costs related to poor quality, but, on the other hand, based on the meagre number of publications on the subject, the attention this issue receives is still unsatisfactory.

Characteristics of the participating companies

Construction companies—especially ISO9000-certified companies—maintain vast information regarding types of defects, their frequency, their severity, their causes, their repair costs, etc. Companies utilize this information for analysing failures and for preventing their reoccurrence. However, this type of information is considered as internal, highly confidential, information that should not be disclosed to others. The in-house analysis of the data only allows the company to compare its present data to its own past data, but lacks the opportunity to relate its data to other companies in the same business (i.e. residential building construction). The results of this study partially fill this information gap. In order to allow cross-comparison of the data from different companies, a systematic categorization method was developed, and the participating companies provided their own data according to a format pre-arranged by the researcher.

The findings of this research are based on data collected from eight construction companies, out of 30 ISO9000-certified companies invited to participate. Considering the sensitivity of the data, this response rate is considered high, since many of the companies were reluctant to disclose their failure rates even though they were guaranteed confidentiality. Low and Yeo (1998) also reported encountering this phenomenon in their quality-related studies. The eight companies included three large, three medium and two small companies, as defined by the financial and organizational indicators presented in Table 1.

Additional characteristics of the eight companies are highlighted in Table 2. These eight companies build together about 13% of the total number of dwelling units built annually in the entire country, thus, although small in number, they constitute a considerable sample size out of the total population. It was practically impossible to get more companies on board at this stage of the research.

Quality-related costs: definitions and their content

The total quality-related costs include elective investments in prevention and appraisal, on the one hand, and the cost of undesired outcomes due to internal and external failures, on the other hand. The former costs are aimed at ensuring quality, while the latter costs are extra expenditures to mend failures that somehow managed to infiltrate through the quality system despite attempts to prevent them. Terms used throughout this study are defined as follows.

Table 1 Size categories of the participating companies

Size category	Annual turnover in New Israeli Shekels (NIS)	Number of simultaneous projects
Small companies	Up to 50 million	1–2
Medium companies	50–100 million	3–10
Large companies	Over 100 million	More than 10

Table 2 Additional characteristics of the participating companies

	Mean	Median	Maximum	Minimum
No. of employees	300	80	1500	15
No. of dwelling units completed per year	490	165	2000	40
No. of simultaneously active construction sites	16	7	70	1
No. of years since ISO9000 certification	4	4	5.5	1.5

Prevention costs

Costs of actions meant to prevent irregularities, defects, mistakes, etc. in the process. Table 3 lists examples of common items in this category, and presents (by titles only) the method used in this study to calculate the sum of their annual costs.

Appraisal costs

Costs of actions taken during the process to ensure conformity to predetermined quality specifications. Table 4 lists common items in this category.

Costs of internal failures

Costs of actions taken to correct irregularities, defects, mistakes, etc. *before* handing over the product to the customer. Table 5 lists examples of common items in this category.

Costs of external failures

Costs of actions taken to correct irregularities, defects, mistakes, etc. *after* handing over the product to the customer. Table 6 lists examples of common items in this category.

Summary of TQRC: total quality-related costs

After completing the four tables with the relevant data, the various quality-related costs can be estimated, the TQRC can be calculated, and various indexes can be established. Table 7 presents such a summary table.

Table 3 Typical items for calculating prevention costs

No.	Description of item	Unit	Monthly quantity	Annual quantity	Cost per unit	Annual cost
1	Cost of the company's quality manager					
2	Cost of quality assurance staff members responsible for centralized activities					
3	Cost of preparing and updating procedures and specifications					
4	Cost of quality control equipment					
5	Cost of internal quality audits					
6	Operating costs of routine process control					
7	Cost of purchasing control planning					
8	Cost of instruction and training on quality-related issues					
9	Cost of accreditation and monitoring of suppliers and subcontractors					
10	Other					
	Total annual prevention costs					

Table 4 Typical items for calculating appraisal costs

No.	Description of item	Unit	Monthly quantity	Annual quantity	Cost per unit	Annual cost
1	Cost of controlling incoming materials and products					
2	Cost of in-process quality control (mainly by the project staff)					
3	Cost of maintenance and calibration of measuring equipment					
4	Cost of routine tests performed at critical stages of the construction process					
5	Cost of comprehensive inspections before handover					
6	Annual costs of external auditing of the quality assurance system					
7	Other					
	Total annual appraisal costs					

Table 5 Typical items for calculating costs of internal failures

No.	Description of item	Unit	Monthly quantity	Annual quantity	Cost per unit	Annual cost
1	Cost of rework (including materials, etc.) during the process					
2	Cost of replacing rejected materials and products					
3	Cost of investigating causes of non-conformances					
4	Penalties or credits for non-conformances					
5	Cost of changes due to non-conformances					
6	Other					
	Total annual internal failures costs					

Table 6 Typical items for calculating costs of external failures

No.	Description of item	Unit	Monthly quantity	Annual quantity	Cost per unit	Annual cost
1	Cost of handling customer complaints					
2	Cost of repairing and amending defects, irregularities, and warranty repairs					
3	Legal costs, compensation and fines					
4	Cost of time invested by company staff in handling post-occupancy non-conformances					
5	Other					
	Total annual costs of external failures					

Table 7 Summary of the total quality-related costs

No.	Description of item	Unit	Monthly quantity	Annual quantity	Cost per unit	Annual cost
1	Prevention costs					
2	Appraisal costs					
3	Costs of internal failures					
4	Costs of external failures					
	Total quality-related costs					

Tables 3–7 are presented here as formats with the appropriate titles an example to follow by future researchers. Confidentiality restrictions prevent disclosure of actual data of individual companies.

Two important indexes were developed relying on the data:

(1) Total quality index=Total quality related costs/Total construction revenues;
(2) Total failure index=Cost of failures/Total construction revenues.

Hidden, intangible, and indirect quality-related costs

The four categories discussed so far are all visible and measurable costs: COQ are tangible expenditures on prevention and appraisal, while CONQ are either actual expenditures, or tangible and measurable damages. These, however, are only part of the picture, or rather the 'tip of the iceberg', since the visible CONQ are always accompanied by substantial additional hidden costs (Feigenbaum, 1991). In addition to the reported internal failure costs, they include, among other things, unreported damages, rework, waste, delays, etc. Similarly, in addition to the directly measurable external failure costs, they also include exposure to future liabilities, failure to retain existing customers, loss of new customers, short-term and long-term damage to reputation, etc. There are no quantitative data on the magnitude of such intangible costs, yet they must not be ignored. Several reputable contractors argued that they might even amount to 10 times the measured CONQ. A rigorous estimate made by this author assumes a much lower factor, which will be discussed later in this paper.

Analysis of the findings

Figure 1 presents all four types of quality-related costs in the eight construction firms, while Figure 2 presents only the directly quantifiable costs of failures, all presented as percentages of each company's construction revenues. Although searched for, no substantial correlation was found between any of the variables mentioned in Tables 2 and 3 (such as size of the company, years of ISO9000 certification, etc.) and the

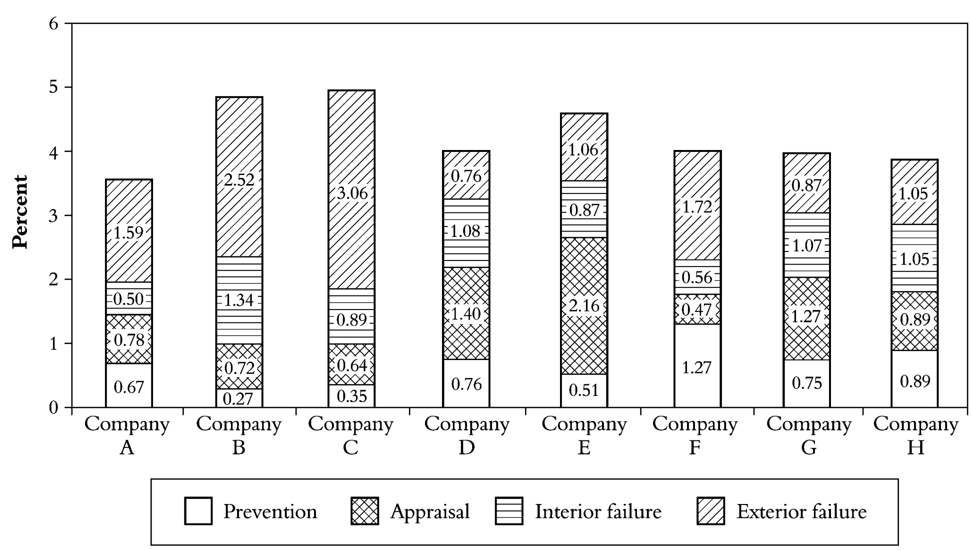

Figure 1 The four components of TQRC as percentages of the company's construction revenue

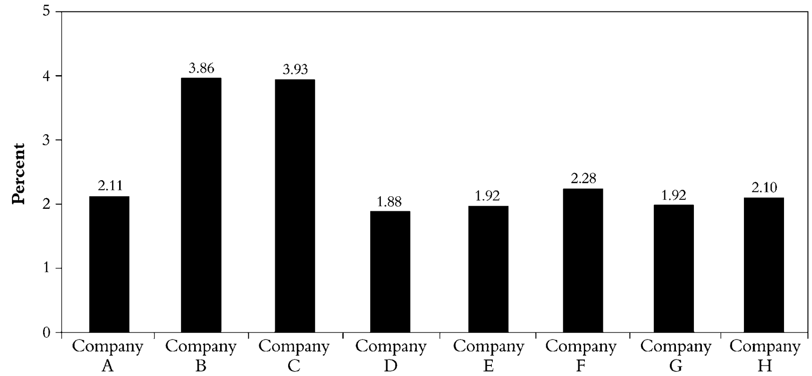

Figure 2 General failure level in the eight companies as a percentage of their revenue

level of expenditure on the various components of the TQRC. It appears that large companies do not spend on prevention and/or appraisal substantially more or less (as percentage of their revenues) than small or medium size companies. Nor is the size of the company related to its expenditure on failures. Similarly, an attempt to correlate the level of expenditures on internal and external failures to the years of ISO9000 certification did not yield any meaningful correlations. The only substantial correlations found are discussed in the following sections.

In Figure 2 firms B and C are conspicuous with their failure costs, which are approximately double the average of the other six firms (~4% versus ~2%). One of these companies is large, and the other is medium—according to the definitions in Table 1. Figure 1 offers a reason for this: it can be seen that these two firms, B and C, were indeed very frugal in their investment in quality costs. They invested no more than 1% of their total revenue in prevention and appraisal. As a result, they accrued ~4% in directly quantifiable costs of non-quality, totalling ~5% in total quality-related costs combined. Most of their counterparts (or, rather, competitors) were more quality-conscious, investing ~2% of their revenues in prevention and appraisal, thus, apparently, cutting their direct failure costs in half, from ~4% to a mere ~2% of their revenues. Hence, their combined quality-related costs totalled ~4% in all. It can be seen that the seemingly tiny difference of 1% in the total quality-related costs is, in fact, not so tiny after all; it constitutes ~20% (!) of the quite common 5% net-profit-to-revenue ratio characteristic of construction firms. The more quality-conscious firms gained at least two advantages over the less quality-conscious ones:

(1) Their total accrued direct quality-related costs amounted to a mere 4% of their total revenue, as opposed to 5% in firms B and C. This means that 1% of their revenue was directly shifted from expenditure to profit.
(2) The internal composition of their total quality-related costs is much healthier and well balanced. They mainly invested money in augmenting their quality culture and ensuring quality, a move that is bound to improve their long-run performance, while firms B and C wasted twice as much money on extra rework and correction of defects. The latter are counter-productive expenditures, with immediate worsening of the company's profitability and with only marginal lessons for the long run.

Although the sample in this research study comprised only eight firms, many lessons may still be learned from analysing the findings. Figure 3 is a scatter diagram that plots the costs of non-quality (Y) versus the costs of quality (X) as percentages of the total construction revenues of each firm. The two companies, B and C, mentioned earlier, lay conspicuously away from the clustering of the other six companies, for a reason. They must not be considered as outliers (statistically), but rather as an integral part of the total picture. They relate to more than a quarter of the total number of dwelling units in the sample (which, by itself, as mentioned earlier, comprises 13% of the total number of dwelling units built annually in the entire country). In fact, the cluster of the other six companies contains a mixture of two large, two medium size and two small companies. They also vary significantly by their ISO9000 certification maturity. These variations reaffirm that the two 'suspected' variables, 'size of company' and 'ISO9000 maturity', have no significant correlation with the companies' expenditure on COQ and/or on CONQ.

Using statistical regression analysis, a clear inverse relation emerges from the data:

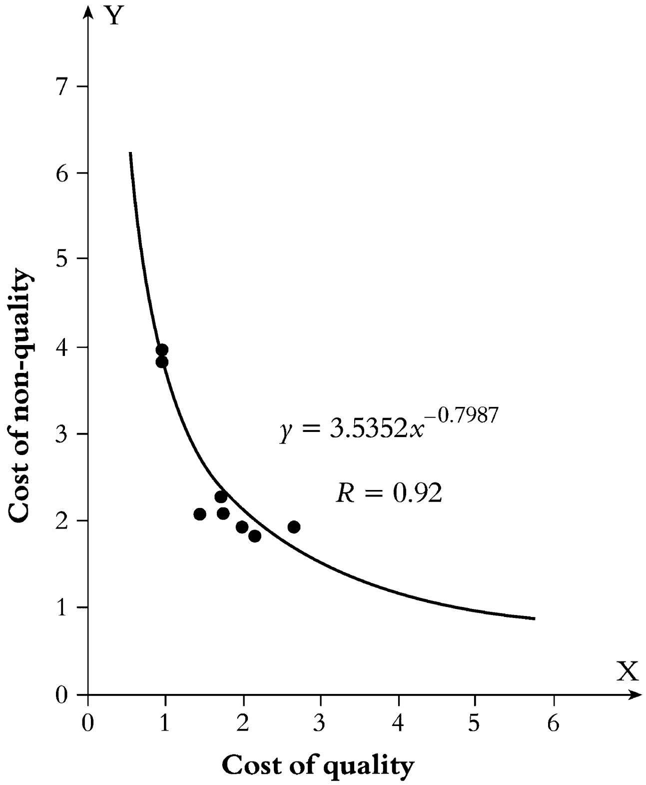

Figure 3 Cost of non-quality (Y) versus cost of quality (X), both as percentages of each company's revenue

$$Y = \frac{A}{X^B} = 3.54X^{-0.80}$$

with a correlation coefficient, r=0.916. Generally, it can be concluded, as reasonably expected, that the more you invest in prevention and appraisal, the less you will have to spend on internal and external failures. Yet, this logic alone is too general and too simplistic, while the diagram can help in confining its boundaries, and determining the crucial balance as reflected in title of this paper.

To determine whether the computed r value (coefficient of correlation) is large enough to be statistically significant for this small sample size, a 't-test' was performed (e.g. Blank, 1980; Pfaffenberger and Patterson, 1987). The computed t-value for a small sample of n=8 and a correlation coefficient r=0.916 is t=5.59. According to the appropriate t-test formula for small samples:

$$t = \frac{r\sqrt{n-2}}{1-r^2} = 5.592$$

To validate the hypothesis H_0: $\rho=0$ versus the hypothesis H_1: $\rho\neq 0$ for t distribution with n=8 and a two-tail $\alpha=0.01$ the acceptance region for H_0 is $|t| \leqslant 3.707$.

Since 5.592>3.707, the hypothesis H_0: $\rho=0$ is rejected, and the correlation between Y and X is significant with a confidence level of at least 99%.

Additional observations can be deduced from the graphical presentation of this mathematical model: an optimal range can be identified, above which further investment is ill spent, and under which a lack of investment is ill saved. It is clear from the graph that in this particular case, investing 2% in quality yields better total results (X+Y≈4) than investing a mere 1% (X+Y≈5), but that investing 4% or more clearly appears to be an 'overdose'. Generally, near the horizontal axis (from about 4% onward in this particular case), the curve is nearly asymptotic, thus there is only a marginal decline in the costs of non-quality for any increase in the costs of quality, thus rendering such investment counterproductive. Similarly, near the vertical axis, as the investment in quality decreases, the penalty rate is extremely high, since the non-quality costs increase at a very steep rate. Thus, an optimum range of investing in prevention and appraisal can easily be found according to the nature of the graph, which appears to be around 2% in this particular case.

In order to validate this observation mathematically, a new function was created:

$$Z = X + Y = X + \frac{A}{X^B} = X + 3.54X^{-0.80}$$

where:

Z=TQRC (total quality-related costs)
X=COQ (cost of quality)
Y=CONQ (cost of non-quality)

Figure 4 presents the total quality-related costs (Z) versus the cost of quality (X), which is the total voluntary investment in prevention and appraisal. As expected, this graph exhibits a clear minimum.

It should be emphasized that the total quality-related costs (Z) must have a minimum value that balances between the proactive investment in quality and the expected consequential damages of non-quality. In this specific case, the values of X and Y that correspond to the minimum value of Z are:

X=1.8% of the company's revenues;
Y=2.25% of the company's revenues;
Z=4.05% of the company's revenues.

The analysis could have been stopped here, leading to the conclusion that the optimum level of investment in COQ is 1.8% of the company's revenues. However, such a conclusion would be too simplistic for the following reason: while the COQ indeed accounts for almost all actual expenditures on prevention and appraisal, the CONQ is missing a great deal of expenditures that are either hidden, intangible or

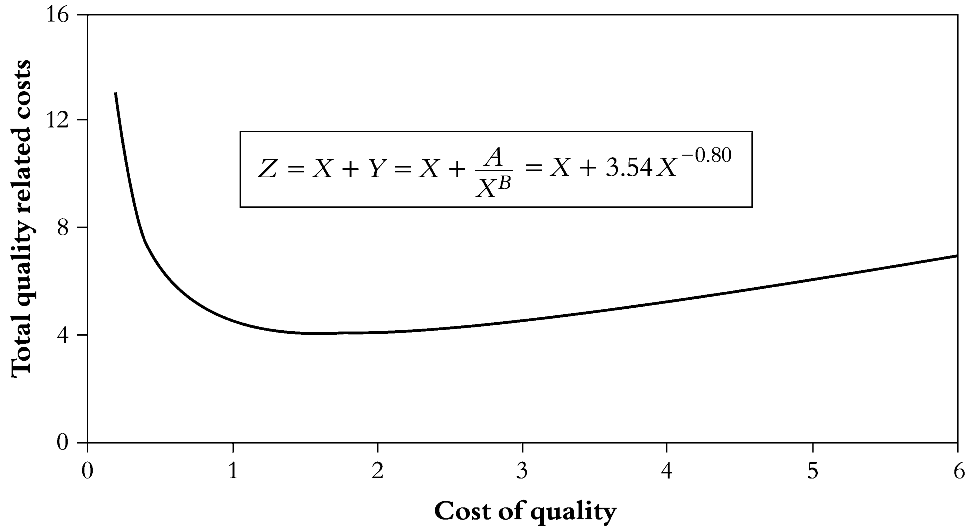

Figure 4 Total quality-related costs (Z) versus cost of quality (X), both as percentages of the company's revenue

indirect. Therefore, 1.8% (according to this sample) is the absolute minimum that should be spent on COQ, but most probably, the optimum level is higher, as elaborated in the next section.

Accounting for hidden, intangible and indirect costs of non-quality

As mentioned earlier, both internal failure and external failure are accompanied by many hidden, unrecorded and indirect costs and consequential damages. When an *internal failure* (i.e. defective work) is detected during the work process, the personnel on site often perform the necessary rework without reporting to anyone, and without leaving any written records. They use the resources, such as labour, materials and equipment available on site, but attribute their cost as if it were a natural part of the normal course of the project. Moreover, in many cases the rework necessitates extension of the project duration (which, in turn, entails additional overhead and financing costs), but, again, the extension is not attributed formally to quality problems. Hence, the true cost of internal failures is, in reality, substantially higher than its formal, directly quantifiable, costs. As a conservative first approximation, it may be assumed to be, at least, equal to the directly measurable costs.

The indirect costs of *external failures* are somewhat similar, but even more severe. Their long-term effects go a long way beyond what meets the eye. They not only involve the technical correction of defects (as in the case of internal failure), but also yield additional negative effects, such as anger, frustration, insult and hostility. In the first circle, the technical correction of building defects in an inhabited house entails much higher direct and indirect costs than in an uninhabited house. In the second circle, there is substantial extra expenditure on opinions of experts (who examine the defects, write reports, suggest remedies, inspect the execution, etc.), legal costs, compensation for consequential damages, and the consumption of invaluable time of managers and officers within the construction company (who are forced to deal urgently with complaining customers of the past, instead of promoting the company's current and future projects). The third circle is the most intangible, yet the most costly—damage to the company's reputation. An unsatisfied customer, naturally, will not buy again from the same company; but in addition, he/she will share the frustrations with many others, thus deterring more potential customers, as well. It is said that a satisfied homebuyer brings at least another one to the same company, while an unsatisfied homebuyer deters at least one. Thus, the aggregated damage is the loss of, at least, two potential customers for each serious case of external failure. As mentioned earlier, the quantification of these three 'circles of damage' is indeed a challenging undertaking. To exemplify their total effect, Figure 5 presents an initial estimate (based on the rough and conservative analysis of a few actual cases), which assumes that their hidden part is equivalent, at least, to three times their measurable part. The numerically calculated cost of a serious case of external failure is, statistically, around 20 000 NIS; while the loss of one potential homebuyer—not two—entails lost profits of, at least, 60 000 NIS. Hence, the minimal factor for external failures should be 4 (80 000 total versus 20 000 tangible).

These mean that in order to reflect, at least partially, the true costs of non-quality (including hidden, indirect

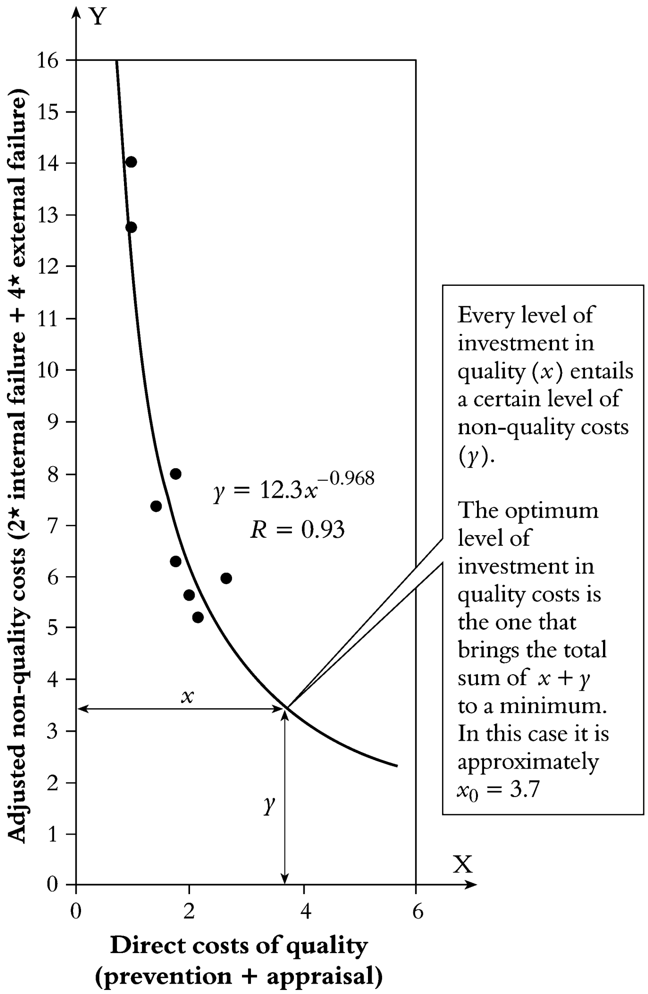

Figure 5 Adjusted costs of non-quality (Y) (including indirect and hidden costs) versus costs of quality (X), both as a percentage of each company's revenue

and long-term costs), the numbers obtained by tangible measurements of non-quality costs must be multiplied by substantial factors (Feigenbaum, 1991). Even very moderate factors, that should be considered as lower limits, such as a factor of 2 for the internal failure costs (assuming that unreported rework, extension of schedule, etc. amount, at least, to the same damage as the reported rework), and a factor of 4 for the external failure costs (based on the previous explanations), will significantly alter the optimum range of proactive investment in quality. As a reasonable exercise, Figure 5 illustrates the strong effect of such an adjustment. The non-quality costs in firms B and C are now 13%–14% of their revenues versus merely 5%–8% in the other firms (rather than ~4% versus ~2% as presented in Figure 3). The meaning of this justified magnification of the costs of non-quality is that the proactive addition of about 1% to the costs of quality (prevention and appraisal) results in more than 6% savings in costs of non-quality. In other words, the sophisticated investment of about 2% (by most of the companies) instead of 1% (by companies B and C) in prevention and appraisal, shifts about 5% (=6%−1%) of the company's revenue from waste (mainly hidden costs of non-quality) to profit. This is, indeed, a major difference. In reality, however, the optimum investment in quality should be much higher than 2%, probably around 4%, as exemplified in Figure 5. Since we cannot yet determine the proper factors for the intangible costs of failure, and since their upper limit is indeed still in question, the only sure statement is that the optimum level of investment is definitely more than 2%. Whether it is around 4%, as in Figure 5, or any other figure, we are unable to determine at this stage.

The message and the practical advice are, therefore, that based on this pilot study, construction firms should *initially* allocate no less than 2% (which should be considered a 'floor') but probably around 4% (which should not necessarily be considered a 'ceiling') of their revenues as proactive investment in quality (prevention and appraisal), depending on the weight each decision maker attributes to the importance and to the eventual magnitude of the extra indirect costs of non-quality. On the one hand, investment of less than the lower limit—2% according to Figure 3—will definitely entail non-quality costs that are too high, even if the intangible costs are totally disregarded. On the other hand, an investment of substantially more than the upper limit—4% according to Figure 5—appears to be a past optimum investment in quality that yields merely marginal benefits.

Since these empirical multiplying factors for the hidden costs are not an exact science, and since a construction company can only regulate its costs of quality, while its costs of non-quality appear only later as consequences, responsible decision makers would be well advised to be closer to the upper limit than to the lower limit, within the recommended investment range. This will definitely curtail the risk of exposure to excessively high, unknown, indirect costs of non-quality. The investigation of the indirect costs of non-quality is, by itself, a fascinating research challenge. At this stage, however, the author is unable to provide more precise, measurement-based multiplying factors. Thus, potential users of this report are encouraged to exercise the 'minimum regret' criterion for their decision-making. If they behave as if their situation is represented by Figure 5, and later find out that their true situation is better represented by Figure 3, they will regret less than in the inverse case.

Conclusions

Several important aspects of quality in construction are revealed by this research:

(1) The total quality-related costs comprise two types of expenditure: voluntary and involuntary. Prevention and appraisal are voluntary expenditures that decision makers can regulate at will. Internal and external failure costs are involuntary expenditures that are imposed upon the company as an undesirable consequence related to their former decisions. The more the firm willingly spends on prevention and appraisal, the less it will be *forced to spend* later on internal and external failures.

(2) There is an optimum range of proactive investment in prevention and appraisal in order to minimize the total quality-related costs. Firms that choose to spend less than the optimum on costs of quality should expect a much higher 'fine' in terms of costs of non-quality, while firms that take the other extreme, and overdo their expenditure on costs of quality, will barely recoup their investment.

(3) Quality failures bear substantial hidden costs. Although they cannot be easily measured, they exist, they cost and they hurt. Among other things, such hidden costs include deterioration of the company's reputation, loss of customers, project delays, increased overheads and liability payments. A company that cares about its long-term performance and reputation must consider the hidden costs as if they were as tangible as the measurable costs.

(4) This topic is of practical interest to the construction industry worldwide, regardless of the specific numbers found in this study. The findings demonstrate that there is a balance to be struck between the proactive cost of quality and the resulting cost of non-quality, and that this balancing number can be empirically determined.

(5) Since the costs of non-quality contain several less tangible items that appear to be largely disregarded in numerical assessments, it appears to be a fruitful idea to expand into this topic in future research studies.

(6) As 'quality in construction' is indeed a universal topic, it is the intention of the author to embark on an international comparative study (utilizing identical methodologies) to derive the actual numbers from a much wider sample, based on numerous worldwide field surveys. The particular findings of the present pilot study (with its small, yet meaningful sample size) should be considered, at this stage, as initial reference numbers based on actual, real life results. Potential partners are invited to participate in such an international study. They must possess the ability to derive from reputable construction firms in their country the confidential data necessary, while guaranteeing the anonymity of the published results.

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