**Zeitschrift:** IABSE reports = Rapports AIPC = IVBH Berichte

**Band:** 47 (1983)

**Artikel:** Quality assurance - a paper tiger?

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**DOI:** https://doi.org/10.5169/seals-36625

# Quality Assurance – A Paper Tiger?

Assurance de la qualité – un tigre de papier?

Qualitätssicherung – Ein Papiertiger?

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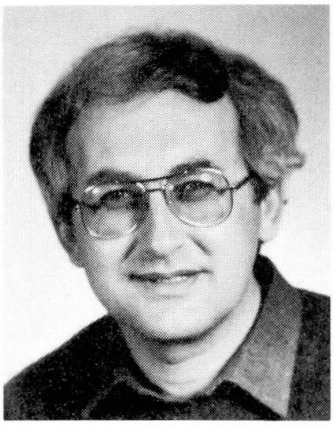

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**SUMMARY**
This report associates quality to the optimal conduct of someones affairs within the constraints set by society. When several egoistic subjects interact on this basis, quality is assured primarily by strategies for the rational resolution of conflicts of interest, and only secondarily by strategies against human errors.

**RESUME**
Ce rapport associe la qualité à la conduite optimale des affaires d'une personne ou d'une organisation dans le cadre des contraintes imposées par la société. Lorsque plusieurs sujets égoïstes agissent dans cet esprit, l'assurance de la qualité résulte primairement de la résolution rationnelle des conflits d'intérêts, et seulement secondairement d'une tentative de lutter contre les erreurs humaines.

**ZUSAMMENFASSUNG**
Dieser Bericht sieht Qualität verbunden mit der optimalen Führung der Geschäfte einer Person oder Organisation in den Grenzen, welche die Gesellschaft setzt. Wirken mehrere egoistische Subjekte zusammen, so besteht Qualitätssicherung in erster Linie aus Strategien zur vernünftigen Bewältigung von Interessenkonflikten, und erst in zweiter Linie aus Strategien zur Vermeidung menschlicher Fehler.

# 1. TERMINOLOGY

In this report, the term 'building' stands for a load-bearing structure and all systems connected to it which may affect its performance or which may be affected by its performance. This includes pavements, surface protection, cladding, bearings, expansion joints in roadways, but also water-drainage systems, thermal and accustic insulation, windows, cranes, .. .

Our interest is on the quality assurance for the load-bearing structure, but it is not possible to abstract from other systems in this context.

In most cases, buildings are custom made prototypes: one-of-a kind solutions to some owner's problem. Consider the set of all thinkable solutions to such a problem. Many of them are impossible structures because they violate natural laws such as equilibrium or material strength. In the subset of possible structures, many are inacceptable to society: they are not safe enough by standards set in technical codes, or they violate other rules set by society in the form of laws or regulations.

On the other hand, only a subset of all thinkable structures is acceptable to the owner; the rest does not conform to his wishes and convictions, which may be influenced by earlier experience.

The intersection of the set of structures acceptable to society with the set of those acceptable to the owner is the set of admissible structures. Obviously, high quality must be sought in this admissible set: Quality structures are always acceptable to society, e.g. always safe, but safe structures need not be of high quality to an owner. Quality is a subjective matter, since the owner sets the standards for the selection of the admissible set (Fig. 1).

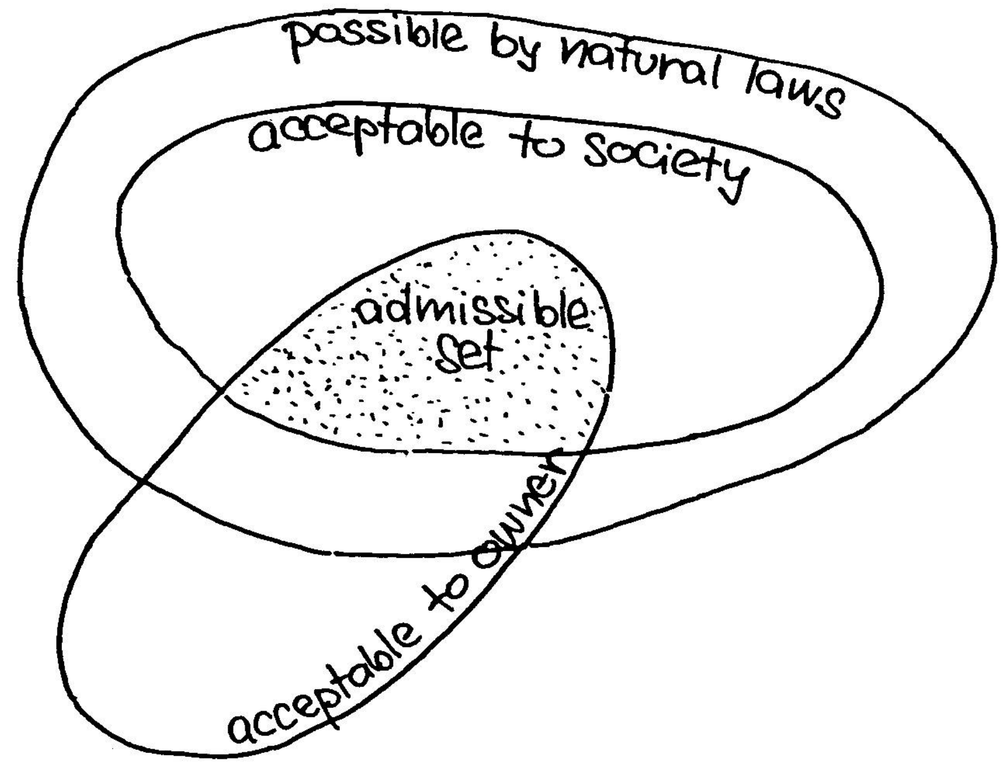


Fig. 1: The admissible set

# 2. QUALITY

## 2.1 Performance

To be useful, a building must conform to certain performance requirements. Most important performance requirements relate to safety, serviceability, and appearance. Malperformance is associated with losses. In the case of safety, losses have mainly the dimension of human life and limb. Malperformance in terms of serviceability and appearance is associated with economic losses.

Structural failure modes cannot be assigned on a general basis to safety, serviceability, or appearance. For example, tightness of a concrete tank can be a safety problem, a serviceability problem, or an appearance problem, depending on the particular situation.

In a well defined setting, loss functions associated with structural performance can be assessed. For example, Reid and Turkstra (1981) estimate the cost of creep failures of floor slabs in office buildings as follows:

$$C_f(\delta/l) = \begin{cases} 0 \quad \$/m^2 & \delta/l \leq 0.002 \\ 4400\,\dfrac{\delta/l-0.002}{0.006} \quad \$/m^2 & 0.002 \leq \delta/l \leq 0.008 \\ 4400 \quad \$/m^2 & \delta/l > 0.008 \end{cases}$$

$\delta$ denotes the deflection, l span. The cost of unserviceability is the sum of the non-structural repair costs and disruption costs in affected levels above and below the floor, and the structural repair cost.

Sudden structural failures result in human losses whenever people populate a building. Beside human losses, there will always be an economic cost for repair.

## 2.2 Utility to the owner

Under usual guarantee clauses, initial serviceability failures as the creep failure example above do not affect the owner: he buys, in principle, a building conforming to performance specifications set in a contract, at some initial cost. Repair of initial failure is covered by the producer and his insurance. More precisely: structures outside the admissible set, but in the set accepted by society, are the producer's problem by contract. Similarly, structures inacceptable to society, e.g. unsafe structures, structural failures, do not, in principle, affect the owner: the producer will be liable, and his insurance will have to pay for the dammage.

Given this legal frame, we may define quality as an optimization concept on the admissible set: Quality is what serves the owner best in the admissible set. In very simple and rather artificial cases, choices between qualitative options in the admissible set can be made on the basis of capitalized cost:

Example: Capitalized replacement costs

Let C denote the initial cost and, for simplicity, the replacement cost of a structure, and t the lifetime of each version of the structure. p is the interest rate. Then, the total cost of initial construction and replacement over a long time is

$$T = C\left[1 + \frac{1}{(1+p)^t} + \frac{1}{(1+p)^{2t}} + \ldots\right] = \frac{C}{1 - \dfrac{1}{(1+p)^t}}$$

Let us now compare two solutions, with initial costs $C_1 > C_2$ and lifetimes $t_1 > t_2$, respectively. Under which conditions is the more durable solution economical?

$$\frac{C_1}{1-\frac{1}{(1+p)^{t_1}}} < \frac{C_2}{1-\frac{1}{1-(1+p)^{t_2}}}$$

or

$$\frac{C_1}{C_2} < \frac{1-\frac{1}{(1+p)^{t_1}}}{1-\frac{1}{(1+p)^{t_2}}}$$

with $p = 5\%$, $t_1 = 20$ years, $t_2 = 10$ years

$$\frac{C_1}{C_2} < 1.61$$

The more durable solution may cost 60% more. With a higher interest rate of 10% and the same lifetimes

$$\frac{C_1}{C_2} < 1.39$$

The more durable solution may cost only 40% more. High interest rates on invested capital thus favor less durable solutions and waste of resources; conservation is linked to low interest rates.

The example may give us a hint at the complexity of the quality issue for a real-life owner. To him, the future lifetime of a design is - at best - a well informed guess of his technical advisors. Interest rates in the future are just plain speculation, and so is the future availability of resources. Moreover, the options in the admissible set differ from each other in many aspects not present in our simple example, such as maintenance costs, operating costs and, most important, operating revenues.

In the real world, stationary external conditions such as those normally assumed in economic models are rare.

In particular, the economic environment and the owner's existential situation may shift over periods much shorter than the buildings lifetime. This may give rise to changes in ownership, changes in maintenance policies, rebuilding, demolition, etc. In spite of the obvious complexity of the owner's real situation, decision theory (see Chernoff and Moses (1959) for an introduction) provides some well defined and useful concepts for the discussion of quality. The most important are utility, a tool for quantification of subjective preferences, and expected utility, a tool for rational subjective decisions under uncertainty.

As a rule buildings do not fail - they are maintained and repaired as long as the owner's utility dictates so, and then replaced by new buildings of greater expected utility.

## 2.3 Quality to the owner

Quality is what serves the owner best in the admissible set. In the language of decision theory, quality is maximum expected utility in the admissible set. For a custom-made prototype and an individual owner of just one such prototype, the definition has conceptual value only. Large institutional owners of many similar buildings may be able to go one step further and truly learn from experience.

Example

Consider the question of integral bridge abutments (Wolde-Tinsea 1983), or specifically: should bridge designs with integral abutments (Fig.2) be prefered over designs with expansion joints (Fig.3). Note that the starting point for asking a meaningful question is some standardization of structural types, as it appears in the two figures.

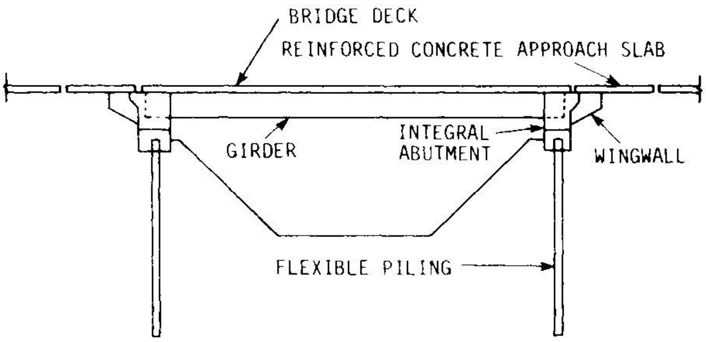


Fig. 2: Bridge with integral abutments

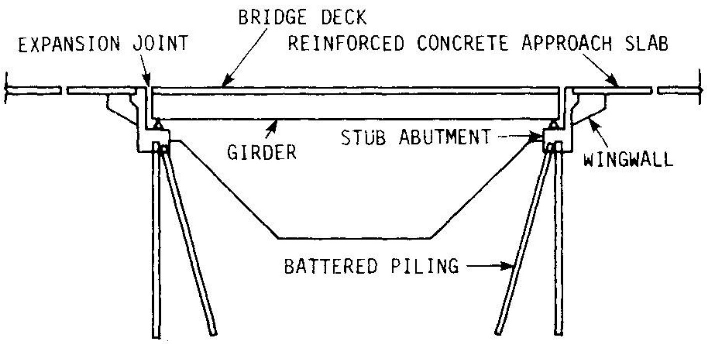


Fig. 3: Bridge with expansion joints

Structural models for the two types can help to make the question more precise, by identifying the relevant mechanical parameters: span, slenderness, abutment height and stiffness, soil properties of backfill, temperature variation, etc. On this background, a public road authority with many bridges of the two types under its control may, in the long run, gain empirical insight into the quality question-learn, in other words, which solution is optimal under which combination of parameters.

The contributions to cost (negative utility) to be monitored would be, in principle

- cost of initial construction
- cost of maintenance and repair, including cost of traffic disruption.

Simple as this may sound, the practical details of auch a monitoring program would require careful study. In particular, it would be necessary to separate initial costs relevant to our alternative from other, site-specific cost elements, and it would be necessary to refer all costs to some unit, e.g. 'costs per lane and per bridge end'.

## 3. QUALITY ASSURANCE?

The definition of quality proposed above identifies quality with optimal control of the building process, from the initial formulation of the owner's intention to design, construction, use, maintenance, repair, remodeling and final demolition.

What does it take to get quality for the owner? We can summarize the general requirements under four headings:

- Communication between owner and producers (planner, contractor) to identify and get across the owner's needs, values, wishes, and to make available his previous experience.

- Creation of the 'best' solution in the terms of the owner.

- Defense of that high quality concept against errors and mistakes in the subsequent building process.

- Learning from experience, along the lines sketched in the example of Section 2.3.

It must be emphasized here that quality to the owner is very much the owner's own business: unless he cares for quality himself, no one will. Nobody optimizes for someone else, and nobody steps in someone else's shoes to learn that other man's lessons .. .

We have, so far, used the word quality with the qualification 'to the owner' - of course, the other actors in the owner's game (Fig. 4) have a quality concept too, but their quality is linked to the optimal conduct of their own affairs, which are not a priori identical with the owner's building process.

What can the owner realistically do to enforce his quality requirements, and to align the producer's quality concepts behind his own? The well-established tools are competition and contractual guarantee. Competition can be used to get the best project from several competing planners, or to get the best bid from competing contractors, or both. Guarantee clauses in contracts - together with quality control - force the contractor to assure quality to the owner for his own benefit.

Learning from experience is more difficult to implement than the items on our list related to one single building. An important point probably is that learning with respect to quality is indeed the owner's business. However, it takes large institutions with a long and stable history, a large field of experience and a professionally qualified staff to learn from experience in a consistent, not just accidental way. Well-managed railroad companies or public road departments are examples of such owners.

The claims of design engineers and contractors to their experience with respect to quality should be taken with some reservation. As a rule, their attention ends with their guarantee. On the other hand, there is some kind of collective learning in the building industry: universities, technical schools, code committees and many informal channels of feedback help us to avoid the most obvious mistakes. More advanced, systemic quality questions, however, cannot be tackled without the initiative of large institutional owners - see again the example in Section 2.3.

Recent work on quality assurance for structures has been centered on strategies against human errors (JCSS 1981). In the light of the definitions proposed here, the claim of that paper to be "a description of a way to rationalize the building process" seems somewhat off target.

The most important tools of quality assurance to the owner in market economies - competition and contractual guarantee - are hardly mentioned in JCSS (1981). However, these indirect strategies are wellknown to work when used intelligently and with attention to details.

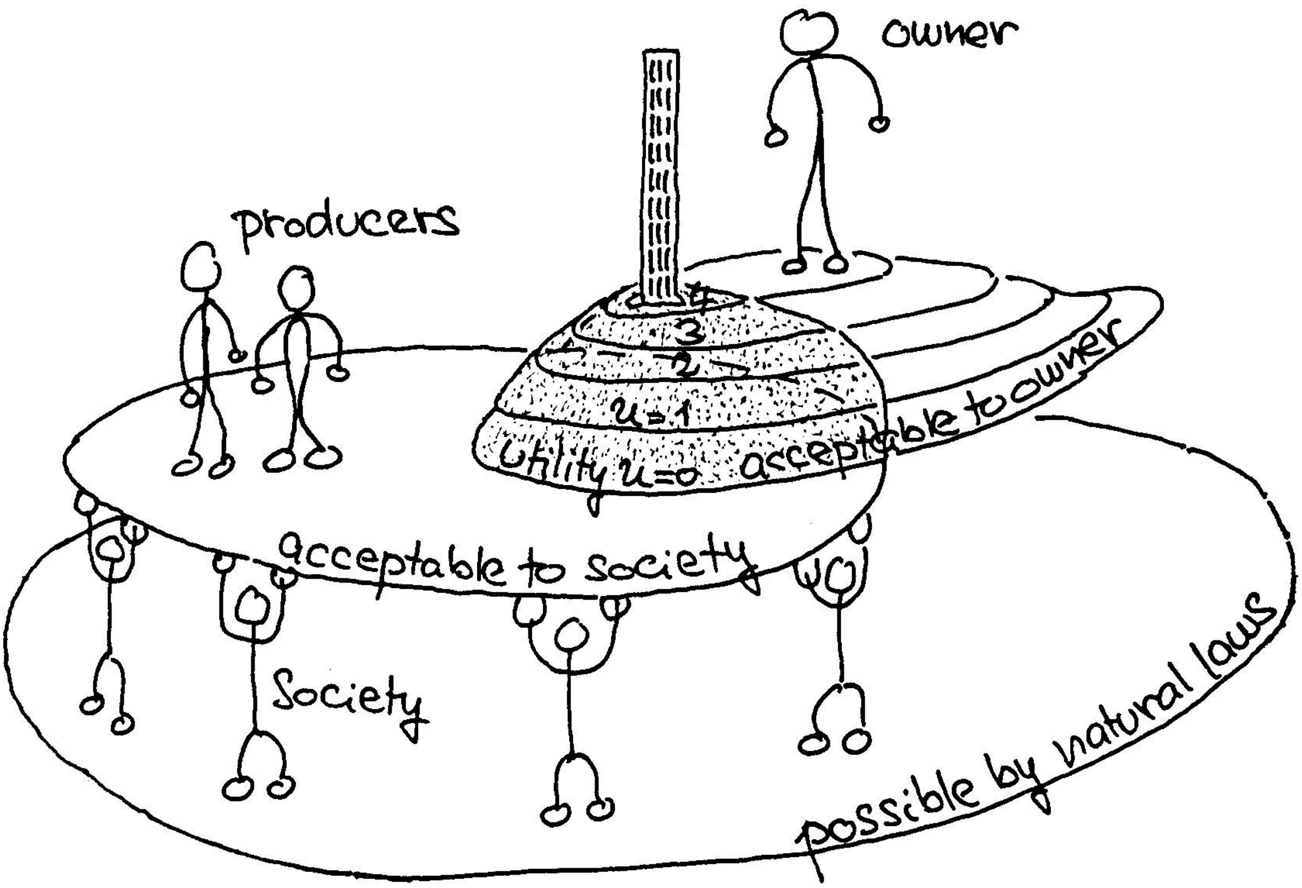


Fig. 4: The owner's game

On the other hand, strategies against human errors are primarily an issue to the producers (engineers, contractors). As such, they should be studied and implemented in the specific context of the producer's optimal conduct of his own business - in analogy to the owner, the producer has an admissible set of operational procedures, and he will choose from them in search of maximum utility to him - his 'quality' is linked to profit and success in a competitive environment. Whether those goals are always best served "by a systematic adherence to written instructions" is certainly an open question. One should keep in mind that bureaucracies, too, tend to optimize for themselves.

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