A CRITICAL APPRAISAL OF CODES AS VEHICLES FOR REALIZING ON-SITE QUALITY

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Abstract

The increasing demand for quality, durability and sustainability requires a critical evaluation of currently used building codes. Although there is no doubt that we need codes, standards, certificates etc., the existence of these documents are no guarantee that the prescribed quality is realized on the building site.

In this paper the essential ingredients for ensuring that the required quality and performance of a structure is realized will be discussed. The responsibility issue will be addressed, as well as a number of other parameters of which the relation with quality is undeniable, but which are still difficult to quantify.

The role of simulation and predictive models and the potential of serious gaming in view of achieving quality goals will be addressed. It will be emphasized that neither codes nor models can replace the responsibility of individuals for the required quality. With respect to the role of codes and models it is remarked that overestimating them may result in unjustified expectations about the performance of a material or structure. Underestimating the role of these tools may lead to scepticism and in the end unjustified negative judgment of the role science may have for enhancing the quality of the built environment.

Keywords: Codes, Models, Performance-based, Prescriptive, Quality, Responsibility, Serious gaming.

1 Introduction

According to Long (2007) our infrastructure accounts for at least 50% of a country’s national wealth. From this he inferred that the performance characteristics and the quality of our infrastructure are of fundamental importance to urban sustainability and the well-being of our environment. Along the same lines Gann (2000) argues: “Construction’s significance to wealth creation and quality of life extends beyond its direct economic contribution. The products create an infrastructure that supports existing and newly emerging social and economic activities”. And he continues saying; “If inadequate or inappropriate buildings and structures are produced, or they are poorly maintained and adapted, then social and economic life is compromised”. These quotes refer to the existing built environment. But enormous challenges are still ahead. The McKinsey Global Institute (Dobbs et al., 2013) has estimated a required investment of $57 trillion in infrastructure worldwide between 2013 and 2030. This figure includes the infrastructure required for transport (roads, ports, rail, airports), water and telecommunications and power plants, and is based on an evaluation of money spent on infrastructure in 84
countries that account for more than 90% of the global GDP. Global investments on aforementioned infrastructure areas have averaged about 3.8% of the global GDP, equivalent to $2.6 trillion in 2013. For growing economies this percentage may be twice as high.

In these figures the costs needed for maintenance, repair and rehabilitation of our existing ageing infrastructure were not included. According to the Office for National Statistics of the UK, 55% of all the money spent in the building industry is spent on new-built, whereas 45% is spent on repair and maintenance (Liles et al. 2008). In The Netherlands the one third of the annual budget for large civil engineering works is spent on inspection, monitoring, maintenance, upgrading and repair. A nation-wide inspection of bridges in the USA has revealed that from the 600,000 bridges one out of four needs to be modernized or repaired. The total amount of money involved in repair and upgrading is estimated at $140,000,000,000 US dollars (Indian Frontier News, 2008). In China 50% of residence buildings require retrofit and 10% urgent intervention (Li et al., 2008). The average service life of civil buildings was reported to be 20-30 years and of marine ports 10-20 years. In most cases this was much less than assumed in the design stage of these structures.

There is no doubt: A reliable infrastructure is a precondition for a society’s quality of life. But at the same time the infrastructure is a burden for the society and for the environment. Both caring for our existing building stock and new-built has a price in terms of energy consumption, emissions and use of raw materials. These are now key-elements in the sustainability debate. In this debate the quality and service life of our infrastructure are crucial topics. Low quality leads to low durability, higher costs for maintenance and repair, high indirect costs for process interruption and production losses during maintenance and repair and shorter service life. This all increases the energy consumption, emission levels and materials use. Against this background it is important to evaluate currently used building codes. Do these codes have the quality to ensure that the required quality of buildings and infrastructure is realised indeed? And what can be expected from a switch from currently used prescriptive performance-based codes to performance-based codes in the debate on quality and – increasingly important! - sustainability?

2 Evolution of codes

2.1 Limitations of codes

It is the designer’s responsibility to design structures that meet a set of predefined criteria. These criteria are formulated in codes and standards and should guarantee a ‘certain’ quality of the end product. A designer should be able to convince approving authorities that his design meets these criteria. This procedure still leaves at least two questions unanswered. The first question concerns the relationship between required quality and produced quality. The second question concerns the correlation between the initially attained quality of a structure and its overall performance over time. In the search for answers to these two questions it is obvious that building codes are indeed important for achieving safety and functionality goals. Recently updated codes may also be valuable tools for achieving ‘modern’ goals regarding energy efficiency, hazardous emissions and sustainability. But, however smart and detailed building codes may be, their existence does not guarantee that the intended quality and performance are realised on the building site. It is not to be expected that thicker codes will make things better.
Quoting Clemmensen (2003): “Regulation is not always the best way of achieving particular goals”. One of the famous Parkinson quotes says: “The last act of a dying organisation is to issue a revised and greatly enlarged rule book” (Reddin, 1990). This quote may exaggerate the situation a bit, but it at least mobilizes reluctance against attempts to implement more and stricter rules. Codes contain minimum criteria for guaranteeing, primarily, the required structural safety. This feature is a strong point of currently used prescriptive codes. However, ensuring code compliance, quality on the building site and accomplishing a variety of societal goals is largely beyond the ‘power’ of prescriptive codes. Again we ask ourselves whether performance-based codes are more powerful in this respect. An answer to this question needs a critical evaluation of the nature of codes in general and their role in the building process.

2.2 The origin of codes

The oldest known building code is found in the Codex of Hammurabi. It dates back to the 18th century BC and contains a few interesting clauses:

- Clause 229: If a builder builds a house for someone, and does not construct it properly, and the house which he built falls in and kills its owner, then that builder shall be put to death.
- Clause 230: If it kills the son of the owner, the son of that builder shall be put to death.
- Clause 232: If it ruins goods, he shall make compensation for all that has been ruined, and inasmuch as he did not construct properly this house which he built and it fell, he shall re-erect the house from his own means.

Note that in these clauses nothing is said about the materials, structural concepts or execution procedures. It is a typical example of a performance-based code! Key-issues in these clauses are safety and responsibility. If the building collapses killing the owner, the builder has to pay with his own life. In case of loss of life the rule is: life for life. In case only material losses were regretted, ‘physical’ compensation was acceptable.

In the fifth bible book Deuteronomy, dated 15th century BC, it has been written: "When you build a new house, then you shall make a battlement for your roof, that you don’t bring blood on your house, if any man fall from there.” In fact this clause goes a step further than the Codex of Hammurabi. Not only the structural safety should be ensured by the builder, but also provisions should be taken aiming at protecting people from accidentally falling from the roof. How the battlement was designed and of what material it was made was not prescribed. Again a typical example of a performance-oriented goal and also in this clause the responsibility issue is explicitly addressed.

These first examples of, in fact, performance-based building codes are followed by Vitruvius’ Ten Books on Architecture in the 1st century BC. Noteworthy is Vitruvius’ observation that the building process had become very complex and multidisciplinary. As a consequence of this the architect, i.e. the builder, could no longer be the expert in all disciplines. While accepting this as a matter of fact, Vitruvius recommended that an architect should have at least some knowledge of all relevant subjects: “Though he need not excel, as Apelles in painting, nor as Myron or Polycletus in sculpture, yet he should have attained some proficiency in these arts. .. Thus also, in other sciences, it is not important that pre-eminence in each be gained, but he must not, however, be ignorant of the general principles of each. For in such a variety of matters, it cannot be supposed that the same person can arrive at excellence in each, since to be aware of their several niceties and bearings, cannot fall within his power”.
Another noteworthy element in Vitruvius’ book is that he considered both hard sciences, such as materials science, mathematics, mechanics and building physics, and social sciences, like philosophy, to be relevant for the building process. About philosophy he stated: “...philosophy makes an architect high-minded and not self-assuming, but rather renders him courteous, just, and honest without avariciousness. This is very important, for no work can be rightly done without honesty and incorruptibility”. Achieving societal goals was not only a matter of rock science, but required a balanced synergy of science and culture, or attitude.

What we learn from these quotes is that the oldest building regulations are typically performance-oriented, while explicitly addressing the responsibility issue. Vitruvius states that the responsibility for the performance of buildings should ideally be in the hands of one person: the architect, but he had to admit that this ideal situation became under pressure due to the increasing complexity and multidisciplinarity of the building process.

2.3 Towards prescriptive codes

In Vitruvius’s days architecture was still considered as one single ‘profession’. Architecture was, by definition, the art and science of designing and constructing buildings and other physical structures for human shelter or use. In “Why is construction so backward” Glendinning (2004) made the observation that during the Renaissance (late Middle Ages) this perception of architecture started to change. Architecture as high art became divorced from architecture as building art. In the centuries that followed this separation between these two elements of architecture – high art and building art - further continued. In the Age of Reason that followed, 17th and 18th century, the real world was considered measurable, weighable and countable. More research and more science were believed to increase our knowledge of the world, even at the smallest scale of observation, and would enable us reshape the reality around us by using and manipulating its “basic building blocks”. Impressive achievements in science and engineering in the 19th and 20th centuries seem to justify this vision. It is obvious that the vision that reality is measureable, weighable and countable is fertile soil for developing prescriptive codes. Current prescriptive codes and regulations, as well as detailed product and process certificates, can be seen as the result of the ‘belief’ that any societal or technical goal can be achieved through ‘engineering’.

There is no doubt: prescriptive codes have been indispensible to realize today’s built environment. In these codes the knowledge about building materials, structural design, detailing and execution procedures has been accumulated and written in such a way that technologists and designers are able to realize structures that meet prescribed criteria, maybe without knowing exactly what is behind each clause of the code. The achievements from the past demonstrate that if researchers have provided code writers with reliable data and if code writers have interpreted this data correctly and if the users of codes, i.e. structural designers, engineers and technologists, have interpreted the codes correctly and if the construction work is executed exactly according to these codes, impressive buildings and structures can be realized. Is seems as if the concept: “follow the codes”, works! It is emphasized, however, that achieving compliance with codes is not given with the quality of the code, but depends on a series of elements beyond science, technique and technology. Building codes are undoubtedly among the key-elements of a strategy to realize buildings, but they only cover a part of the whole building process. In order to ensure on-site quality, long-term performance of structures
and that, on top of that, also societal building goals are met, a more comprehensive quality strategy is required. The replacement of prescriptive building codes by performance-based codes might be a step in this direction (Clemmensen, 2003).

2.4 Back to performance-based codes

Several reasons have been mentioned for the switch from prescriptive codes to ‘modern’ performance-based codes. Foliente (2000) even called these reasons fundamental difficulties. The most serious problem with the prescriptive approach would be that it serves as a barrier to innovation. Another problem would be that the prescriptive approach makes it very difficult to cost-optimize building construction. A third difficulty is to establish fair trading agreements. None of these three reasons, however, address the problem that prescriptive codes are not appropriate tools to guarantee that a required quality is achieved. It thus seems that the switch from prescriptive to performance-based codes is not primarily quality-driven. Whether there is hope to expect a positive effect on on-site quality from the switch to performance-based codes is, therefore, still an open question.

What we can expect from a change of codes can be learned best if put the question in a historical perspective. A code is, in a way, a mirror of the past. In the previous paragraph we saw that the prescriptive code reflects the period that reality became decomposed in basic building blocks: countable, measurable and weighable. There was nothing more than that. From basic building blocks a new world could be built. A prescriptive code could cover everything needed for building a new (perfect) world. Follow the code, and you will harvest whatever you desire, including quality! This vision, however, has met its Waterloo. The shift from prescriptive codes back to performance-based codes can be considered as a capitulation of the “belief” in “technical fix” solutions. A code as such does not guarantee quality; neither can it be hold accountable for lack of quality. The major reason for the switch of codes did not concern the quality aspect, but the accountability aspect. In modern performance-based codes the builder is - like in the past - held responsible again for the quality and long-term performance of the end product. The question remains, however, whether a switch of type of codes will automatically result in higher quality if not quality, but accountability was the main driver behind this switch.

3 A META-Code for ensuring on-site quality

When speaking about quality it has to be emphasized that this term does not only concern structural safety and stability, but also elements like durability and service life, energy efficiency, sustainability and aesthetics. By listing these elements and admitting that they should all be considered in a modern comprehensive building industry, we are essentially back in Vitruvius times, when construction was considered a multidisciplinary activity with the focus on overall quality of life. If construction is so inherently multidisciplinary, involving both technical and non-technical aspects, a comprehensive building code should be multi-disciplinary as well. Such a code should include a prescriptive part, but in addition to that also a part dealing with a number of intangible factors that have proven to be essential for achieving quality and additional objectives of contemporary building processes. Intangible factors are not measurable or weighable in the same way as ‘hard parameters’, like concrete
compressive strength, cover depth and permeability. Intangible factors are generally grouped together under the heading ‘human factor’. What is needed for ensuring integral quality is a meta-code, in which both tangible (prescriptive) and intangible elements are addressed in a balanced way. Like in the term metaphysics the prefix ‘meta’ stands for “beyond”, i.e. beyond physics, the meaning of this prefix in meta-code points to elements beyond those formulated in prescriptive and/or performance-based codes.

4 DREAM CODE: Example of a meta-code for ensuring on-site quality

4.1 Basic elements of a meta-code for integral quality

A meta-code for accomplishing multi-dimensional objectives, i.e. safety, durability, economy, sustainability, aesthetics etc, of modern building projects is a concept, or approach, rather than a rule book exclusively dealing with materials, mechanics and detailing. In the following the additional elements of the meta-code are brought together in the acronym “DREAM CODE” (Van Breugel, 2008). This acronym stands for: Dedication & Discipline; Responsibility & Risk; Expertise & Execution; Awareness & Accountability; Materials, Modelling and Managing; Codes, Control, Certificates and Communication; Organisation; Design & Detailing and Economy & Education. Together these elements form a ‘quality chain’ that bridges the gap between theory and practice, as schematically shown in Fig. 1. In the following paragraphs these factors will be briefly discussed. Particular attention will be paid to the role of models as potential integrators of tangible and intangible elements of the meta-code and vehicles for communication, education and training.

4.2 Dedication and Discipline

A first element of the DREAM CODE for realising on-site quality is Dedication. All parties involved in the building process should be dedicated and motivated. To keep people motivated
it is essential that the distance of craftsman to the final product remains as short as possible. Quality management should focus on restoring and maintaining the relationship between the craftsman and his product. “... industrializing the future will only work if we are able to attain a precision and complexity at least as impressive as what was achieved by the trained craftsmen in the past (Ingenhoven, 2003)”. The more fragmented the complex building process is, the more difficult it will be to convince individual workers of the relevance of the quality of their work for the quality of the end product. To keep everybody connected and motivated, appropriate modern communication tools should be used - a key-tasks for project managers.

Without discipline the risk of weak links in the quality chain is imminent. When a lack of discipline causes failures the costs for repair will generally be much higher than the extra costs for maintaining discipline. For demonstrating the importance of discipline simulation models can be of great help. These models can clearly demonstrate, for example, the effect of delays in the building process caused by lack of discipline. In this way simulation models can teach us that working in a disciplined way finally pays off!

4.2 Risk & Responsibility

With performance-based codes the responsibility for code compliance is one-sided on the shoulders of the builder. The latter will only be prepared to accept this responsibility if he knows the risk he takes. Risk management will, therefore, become an essential part of the builder’s policy. This even more in DBFM(Design-Built-Finance-Maintain)-contracts, where the contractor is responsible for proper functioning of a structure over a long period of time. In order to reduce the risk, the builder may be challenged to search for either innovative solutions or just traditional proven concepts (risk aversion!).

For all workers it holds that taking responsibility for their contribution in the building process will become easier if they have a clear picture of the importance of their particular role for achieving quality goals. In this respect it is important that they get feedback, so that they can reflect on the consequences of errors for the quality of the end product. For example, designers should visit building sites and see how difficult it can be to realize their thoroughly debated, but sometimes too sophisticated construction details.

4.3 Expertise & Execution

Dedicated people, who are trained to work in a disciplined way and are fully aware of their responsibilities, but don’t have the appropriate expertise, will not be able to produce good quality. However, it will be just their dedication and sense of responsibility that will motivate them to reflect on their own expertise and competences and to take steps to attract possible lacking expertise from elsewhere.

Crucial for achieving quality is the execution process. Pouring of concrete, slip forming, curing and finishing of concrete are all activities that require expertise and specific skills. The required expertise and skills presuppose continuous training of workers and understanding of the consequences of their specific role in the building process in view of quality.
4.4 Awareness and Accountability

Architects and designers should be aware of the huge impact of the building industry on the environment. Excessive energy consumption and use of raw materials beyond what is needed to accomplish the required function of a building or structure do not go together with a contribution to the quality of life. This awareness should motivate designers to minimize energy and material consumption. Moreover, all partners in the project should be aware of the consequences of poor execution for maintenance, repair and even premature demolishing of poorly executed structures. Premature repair, or even demolishing of structures violate sustainability goals.

Who is held accountable for what has a large influence of the builders preparedness to take risks and to innovate. If a contractor is held accountable for the failure or success of an innovation he may decide to fall back on traditional low-risk solutions. If an owner and contractor share the risk of an innovation, a contractor will be less reluctant to invest in innovative solutions.

4.5 Materials, Models and Management

Only 10% of construction deficiencies are caused by the use of faulty materials (Bonshor et al, 1982). Materials, thus, do not seem to constitute a big quality problem. Whether this is also true for new materials is still an open question. For many new building materials their performance over time is still not known. This is the case for most of the recently proposed blended cement-based materials. It is hard to predict the long-term performance of structures made with these materials. Fundamental multiscale models, which describe the relevant (degradation) mechanisms and processes on a fundamental level, i.e. at the microlevel or even nanolevel, will become increasingly important for making reliable predictions of the performance of materials and structures over time (Slater, et al, 1999, Van Breugel, 2000, 2005). Without models it will be even impossible to perform reliable service life predictions. Moreover, models are essential for simulation and optimization of the entire building process. Models can support decision-making processes in subsequent stage of the building process and can thus act as an important management tool. Whether this will result in higher quality depends, of course, on the quality of the models and on the correct use of them. Not much can be expected from the use of models by managers who don’t have the basic knowledge of the building process.

The importance of good management in view of quality can hardly be overestimated. Poor management and negligence can easily undo the craftsman’s potential to produce good quality. Note that 99% of quality-related costs are due to carelessness of designers and workers and poor site management (King, 2000). For managers there is, therefore, a world to win with good site management.

4.6 Codes, Control, Certificates, Communication

As noticed already by Vitruvius (85-20 BC), the complexity of the building process makes it impossible to be an expert in all aspects of design and execution. In many situations we need to rely on the expertise of others. We have to rely on documents, i.e. codes and certificates, produced by experts in relevant fields. These documents are communication tools, through which knowledge and expertise in a particular discipline are made accessible for other
disciplines. Codes give descriptions of materials behaviour, structural behaviour and detailing. Certificates guarantee that the quality of a material, a procedure or a service is in accordance with the specifications. However, neither codes nor certificates can replace the designer’s responsibility for the choices he or she has to make. In the complex design and building process codes and certificates are valuable tools, but only in the hands of well educated people who know how to use them.

In all building activities the factor man is dominantly present. Human beings are not perfect, and even the most dedicated employees can make a mistake. Therefore control remains needed. Control is not just a check whether and how people do their job, but should be considered as an inherent part of teamwork. The need and presence of control mechanisms show that an organisation is aware of the fallibility of their employees and tries to anticipate on the occurrence of costly errors.

4.7 Organisation

A prerequisite for achieving quality is the understanding that the building process is organized teamwork. Teamwork makes the difference between success and failure. For example, speaking about concrete, Simons (1991) stated that teamwork is the invisible ingredient in high strength concrete. This is true for producing high strength concrete, but in fact it holds for the whole building process. Teamwork presupposes that experts from different disciplines are prepared to invest beyond their own territory. Investing in other disciplines and communicating with other experts is not only the basis for good quality, but often it is also the first step to innovation. The reverse is true as well. Poor organization of communication lines between disciplines is often the cause of premature failure (Harrison, 1991)”.

4.8 Design and Detailing

Design and detailing are crucial for both safety and quality. A poor design does not only jeopardize the structural safety, but might also give rise to miscommunication, questionable decisions and loss of commitment of workers who intuitively judge the design to be poor because of the many uncommon details. Poor design and detailing are often caused by misinterpretation of building codes and recommendations. Design and detailing are generally appropriately dealt with in prescriptive codes.

4.9 Education and Economy

Education involves transfer of knowledge and skills, but also training of people. The rapid introduction of new types of concrete, for example, requires continuous training of designers, concrete technologists and workers on the building site.

Advanced predictive and simulation models can play a significant role in educating people. With these models many details of the materials behaviour and of the production process can be simulated and the importance of both tangible and intangible parameters addressed in the DREAM CODE can be demonstrated, analysed and evaluated.

The use of advanced software for education and training of people as a tool to improve quality on the building site is still in its early stage. In the future the role of IT in the building process will certainly increase. Evolutions in, for example, concrete curing control systems and BIM are typical examples of IT-based technologies aiming at both quality and economy.
It is believed that serious gaming is the next logic step towards IT-based support of a quality-driven building process. The building process is a serious game! Serious games have the potential to incorporate and link advanced numerical models for simulating different stages of the execution process (i.e. curing control systems), structural performance, degradation processes, service life prediction, etc. in such a way that the whole building process and service life can be simulated. The consequences of decisions made in any stage of the design and execution process can be simulated and evaluated. This feature of serious games makes them powerful vehicles for creating awareness, for motivating people, for reflection on design decisions, for training of architects, designers and craftsmen, for (virtual) shortening of the distance between specific actions of workers and the effect of that action on the quality of the final product. The development and implementation of these tools will take time and will cost money. However, the obtained increase in quality will more than compensate for these initial expenses (Wolfseher, 1998).

5 Conclusions

For shaping our built environment building codes are indispensible. Yet, the quality desired and presumed in building codes is not automatically identical with the quality produced on the building site. The on-site quality is the result of an organic process, consisting of tangible and intangible (human) factors. Tangible factors can be dealt with in prescriptive codes. Much better than prescriptive codes performance-based codes have the potential to accommodate intangible factors as well. However, there is no guarantee that intangible factors will be addressed in the latter indeed, since the step to performance-based codes seems to be primarily accountability-driven and not quality-driven.

The type of code that could involve both tangible and intangible factors is called a meta-code. A meta-code is a concept, an approach, rather than a rule book. Interactive simulation models, predictive models, and even more serious games that rely on these models, are considered appropriate vehicles for bringing tangible and intangible factors together and making existing knowledge and expertise accessible and operational for all actors in the building process.

Rowe (1981) once quoted Michelangelo who must have said: “The contractor’s most blessed money is the money spent on models”. The use of simulation and predictive models and serious games fits in Michelangelo’s vision. Models are not identical with reality, neither with the building process, but they are valuable tools for education and training, for creating awareness and for detecting the vital stages of the building process which may compromise the produced quality. Hence, models and serious games can prevent errors, increase quality, reduce maintenance costs, increase service life and reduce the impact of the building process on the environment. Indeed: blessed money!

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