The Nature of Theory and Design

By Jon A. Schmidt, P.E., SECB

My title this month is also the subtitle of a book (*Structural Engineering: The Nature of Theory and Design*, New York: Ellis Horwood, 1990) by William Addis, a British author who has written extensively on the history and philosophy of civil and (especially) structural engineering. I only came across it recently, but after reading it (twice), I cannot recommend it highly enough.

The text begins with a discussion of the common dichotomy that is perceived between theory and practice, and the call that has sounded for more than a century to "bridge the gap". Addis argues that this approach is fundamentally flawed and should be replaced by one that recognizes three categories: engineering science, engineering design, and construction. The distinction between engineering science and engineering design is especially important, because their objectives are very different – something that is not as widely acknowledged as it should be.

In fact, Addis identifies two sets of definitions for "theory" and "practice", resulting in six potential "gaps" that may need to be "bridged". There is a surprisingly common misconception, even among architects and engineers, "that engineering design depends utterly upon theory of some kind ... and its ultimate aim is to predict exactly the supposed stresses and strains under load." Instead, we should "consider theoretical calculations to be of secondary importance to a different type of knowledge ... based upon an understanding of how structures behave, rather than upon the abstract principles, laws or theories which are supposed to govern their behaviour."

Addis calls the process by which an engineer takes a structure from conception to reality a "design procedure". The inputs are knowledge and experience; the constraints include client requirements, costs, time, codes and standards, and construction methods; and the results are two specific outputs: description and justification. First, "A designer must be able to communicate his design to the people who are to make or build it." For structural engineers, this is usually accomplished by means of drawings and specifications. Second, "It is absolutely necessary to be able to provide a convincing argument to justify a design to the many persons who have an interest in the matter ... not least, the designer(s) themselves."

As an aside, an often-touted potential benefit of building information modeling (BIM) – although it is not necessarily expressed in these terms – is the unification of the description and justification of structural engineering design. Ideally, the same model can be used to facilitate both, but it still remains to be seen whether the two different objectives can consistently be achieved in this way without compromising their distinct requirements.

A design procedure does not lead inevitably to a particular outcome. Addis notes "that it is possible to produce very similar structural designs using different design procedures and that similar design procedures can lead to significantly different structures – there is no logical connection between the two." He likens the "acts of creation" in which structural engineers routinely engage to the composition of music, because both involve arranging a limited number of building blocks – for us, "the beam, the arch, the tie, the shell and so on" – that can be combined in a nearly infinite number of ways.

Addis goes on to make the interesting observation that engineers actually create three independent models for the analysis of every structure – one for the materials, one for the individual components and their arrangement, and one for the loads. Assumptions and uncertainties are inherent in each of these, and they are not always easily reconciled with the "real world". Is steel truly linearly elastic up to a specified yield strength? Do node coordinates always coincide exactly with actual joint work points? Does wind really exert a constant static pressure normal to each exterior face of a building?

Ultimately, each designer has a unique point of view that informs how he or she "sees" a structure. Certain concepts, like flexure and shear, are familiar to all of us as convenient ways of characterizing structural behavior. However, we also develop and refine a certain amount of technical intuition – "tacit" knowledge that is difficult to capture and communicate to others – through our individual professional experiences.

As a consequence of all this, two models of the same structure can both be "correct", yet yield different results. The advantage that an engineering designer has over an engineering scientist is the ability not only to adjust the model to represent reality better, but also to adjust reality to suit the model better – yet another example of what we practice being more of an art than a science.▪

Your Turn

What do you see as the key obstacles to integrating the description and justification of a structural design by means of a single building information model (BIM)? What are some other assumptions that you commonly make when creating structural analysis models? Have you ever "adjusted reality" to accommodate a particular model? If so, how? Please submit your responses and see what others have had to say by clicking on the "Your Turn" button at **www.STRUCTUREmag.org**.

*Jon A. Schmidt, P.E., SECB (**chair@STRUCTUREmag.org**), is an associate structural engineer at Burns & McDonnell in Kansas City, Missouri, and chairs the STRUCTURE magazine Editorial Board.*