SECTION

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CHAPTER

1

THE NEED FOR DESIGN THEORY RESEARCH

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"Engineers do design" – a factual statement made by many both inside and outside of the engineering community. The statement has been the basis of speeches by William Wulf, President of the National Academy of Engineering; by John Brighton, Assistant Director for Engineering at the National Science Foundation (NSF); and by industry leaders commenting on the current outsourcing of manufacturing and, now increasingly, some engineering design jobs overseas. Design permeates the activities of all engineering disciplines: Civil Engineers working on large-scale infrastructure systems in transportation; bioengineers creating new sensors for human health monitoring; mechanical engineers developing new alternative energy sources and power trains for the hydrogen economy; and electrical engineers linking information and communications networks through new advances in photonics. So if all engineers are already doing design, why do we need a program that supports design theory research? Given that engineering design crosses all the disciplinary domains in engineering, our challenge is to focus on creating the new knowledge, advancing the support tools, and building the necessary principles and foundations into a domain-neutral framework that enables engineers to meet the future needs of society. As a research community, a design research program is needed to continue our work to establish the set of principles that underlie all design, such as:

Design requires a clearly stated objective function.
Design must address the uncertainties within all aspects of the system to better inform the decision-making.

Over the past three decades, design theory research has taken several twists and turns, as computational tools became the standard for how engineers of all disciplines "did design." In an early NSF Workshop report, ***Design Theory '88*** [1], research was categorized into topical areas focused on the design process that included the computational modeling; the cognitive and social aspects; the representations and environments; the analysis tools including optimization and the design "for" such as "for manufacturing." At that time, the NSF program was called Design Theory and Methodology and consisted of three components that essentially captured these five topical areas: The first, Scientifically Sound Theories of Design, established a home for proposals that were directed at creating the scientific basis for the design process. The second, Foundations for Design Environments, was aimed at advancing the understanding of fundamental generic principles that could be used and understood across engineering domains. The third, Design Processes, was focused on the how and why of the design process, including early work on life-cycle concepts and concurrent design.

At this point, you may ask, "So what is new?" The tools certainly have advanced over the years, from early computer-aided design (CAD) through solid modeling capability. The introduction of virtual reality, computer integration engineering, and collaborative and distributed design processes created demands upon the community to focus on how decisions were made, under what conditions and to what purpose. Decision-based design became a major thrust for the research community, with the issues of uncertainty and predictive modeling capability becoming the foci. As with any science, the theories must be put forward, tested for consistency and completeness, and then incorporated (or not) into the framework of the science. This is true, too, for engineering design, if it is to become more than just an ad hoc, intuitive process that is domain-specific. In response, the **Open Workshops on Decision-Based Design** [2], a series of face-to-face and website workshops, addressed the spectrum of issues that were raised.

These activities demonstrated that decision-based design creates a challenging avenue for research that encompasses:

(1) the cognitive "structuring" of a problem
(2) the drive for innovation where the existing "structure" or solution space is ill-defined or insufficient
(3) the need to reduce complexity by mapping to what we know
(4) the consistent use of decision technologies to optimize the decision-making capabilities within the design space we have created.

As socially and technically responsible engineers, we must be able to demonstrate that we have searched and populated the design space with the necessary and appropriate data and information, that we have considered the risks and the odds to an appropriate level, that we have created and/or integrated models that capture the intent of the design (design informatics), that these models can be validated and that we have reduced the potential for unintended outcomes to the best of our capability.

If design were easy, then the following eight sections of this book would be unnecessary. Engineering implies doing something, and this moves us beyond the regime of descriptive, theoretical study into the need for predictive action. This leads to the challenges addressed in sections 2, 3 and 5, where the difficulty often comes down to eliciting the answer to the simple question, "What do you want?" If we could come up with a single equation that represented the design objective, and solve this equation in closed analytical form, then sections 6 and 7 would be redundant, and the differences of perspective would be resolved. If all modeling were predicative rather than descriptive, then computer software tools would take care of all Section 8 validation methods. Finally, if we could just engineer without the consideration of economics, well, that wouldn't be "good" engineering, and so the methods addressed in Section 4 become critical to the realization of viable products and systems.

Finally, in looking toward our future, the vision statement from the recent ***ED 2030: Strategic Planning for Engineering Design*** [3], includes the following: "*In 2030, designers will work synergistically within design environments focused on design not distracted by the underlying computing infrastructure. Designers will interact in task-appropriate, human terms and language with no particular distinction between communicating with another human team member or online computer design tools. Such environments will amplify human creativity leading toward innovation-guided design. Future design tools and methods will not only support analysis and decision–making from a technological point of view, but will also account for psychological, sociological, and anthropological factors based on fundamental understanding of these factors and their interaction. … Designers will effortlessly and effectively explore vast and complex design spaces. Design will go from incremental changes and improvements to great bold advances. Therefore design will be an exciting activity fully engaging our full human creative abilities.*"

REFERENCES

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2. Open Workshops on Decision-Based Design, http://dbd.eng.buffalo.edu/.
3. ED2030: Strategic Planning for Engineering Design*, 2004*. Report on NSF Workshop, March 26–29, AZ.