Journal of Mechanical Design

Guest Editorial

New Perspectives on Design Automation: Celebrating the 40th Anniversary of the ASME Design Automation Conference

1 Introduction

The ASME Design Automation Conference and Committee (DAC) were initiated more than 40 years ago by a group of engineering visionaries to mark the dawn of the computer era in engineering design. Along the way, a strong and diverse community of academic, industrial, and government researchers have made the DAC community what it is today: a vibrant and energetic research community and a place to share the thoughts and ideas that fuel a common passion for engineering design automation (DA).

To celebrate the legacy of the DAC and to spark common visions of the DAC's future, the Design Automation Committee organized a 40th anniversary symposium at the 2014 *ASME International Design Engineering Technical Conferences* (IDETC). A capacity crowd of hundreds of DA researchers attended the program, which was organized into three segments. First, Kenneth Ragsdell, one of the founding members of the DAC, spoke of the founding of the conference and committee. He was followed by Panos Papalambros and Farrokh Mistree, who described the impact of 40 years of DA research and education along with some thoughts on the future of the DAC. The program ended with a series of six lightning talks from early career members of the DAC community offering their vision of emerging research opportunities in DA.

2 The Early Days of the DAC

Kenneth Ragsdell, one of the earliest leaders of the DAC, recounted the early days of DAC. Ragsdell recalled that among the early members and founders of the DAC, there was a prevailing opinion that design is the essence of engineering and that the digital computer was revolutionizing the practice of design engineering. In his 1980 editorial in the *ASME Journal of Mechanical Design* [1], written after attending the fifth DAC in 1979, then ASME President Donald Zwiep recognized the importance of mechanical design and DA in particular. "If I were given one word to describe a principal function of engineering, that word would be *design* for it is a dynamic word describing a philosophy and an operation that has enabled the practitioners of engineering to continuously improve our way of life." At a time when mechanical engineers were subject to significant public scrutiny in light of recent events, such as the Three Mile Island incident, he noted that ASME was "now in a new ball game … And that new ball game is what DA is all about. Optimum design sessions, such as (the ones) held in St. Louis last September (1979) emphasizing theory and practice, techniques, (and) algorithms, … are what the founders of our Society had in mind almost 100 years ago …"

When Ali Seireg and colleagues founded the DAC in 1974, the goal was to provide a forum for greater emphasis on computers and their growing impact on the practice of design engineering. After significant discussion, Ragsdell recalled, they decided to initially emphasize the following areas [2]:

- Machine design applications
- Design optimization and numerical methods
- computer graphics and drafting
- hardware–software system evaluation
- man–machine interaction
- finite element analysis
- computer-aided design (CAD)/computer-aided manufacturing (CAM) systems
- intelligent machines and robotics

Upon naming the new committee the "Design Automation Committee", the members reflected on what the name meant. Did it mean "automation of the design process?" Did it mean "design of automation systems?" Did it mean something else? Ultimately, they said "yes" to all of these questions, and focused on attracting outstanding authors, excellent papers, and good reviewers. Although the areas mentioned above were of particular interest, the founders decided to be *very* open to new areas that they had not anticipated, with an emphasis on encouraging young investigators. The founders observed that many technical committees become closed communities over time, and they did not want that to happen to the DAC. Furthermore, the early members attributed much of their success to a combination of young investigators and senior scholars—a combination that helped attract others to the activities of the committee. Early thought leaders in the 1970s included Ali Seireg, Ken Ragsdell, Doug Wilde, James Siddall, S. S. Rao, Miles Townsend, Roger Mayne, Edward Haug, and many others. Ali Seireg, who was recognized as a leader in the application of optimization techniques to the design of mechanical devices and systems, served as the founding chair of the Design Automation Committee.

Prior to the establishment of the *ASME Journal of Mechanical Design* in 1978, DA journal papers were scattered in publications throughout the field of engineering and in other ASME transaction journals. The establishment of the *Journal of Mechanical Design* was an important event in the development of the DAC, since it provided a home for its technical publications. To gain a sense of the earliest research in the DAC, it is thought-provoking to review volume 102, issue 3, published in 1980. With an overview by Ragsdell [2], the committee chair at the time, the issue included 23 papers that originated in the DAC. Topics included goal programing, dynamic programing, monotonicity analysis for global optimal design, decomposition strategies for large nonlinear problems, methods for generating and manipulating curved surfaces and graphical environments for computer aided design, a graphical package for analyzing and synthesizing linkages, and many other topics that continue to influence DA research and practice today.

3 Four Decades of DA Research and Education

Panos Papalambros and Farrokh Mistree have been two of the most consistent thought-leaders in DA over the past four decades, and their students are continuing that legacy into the future. Both professors reflected upon their decades of involvement in DAC and their visions for the future of DAC.

Papalambros began by asking the question: "Has DAC really been successful?" His answer was emphatically affirmative. As a clear indication of success, he cited the abundance of young design researchers and teachers in DAC 40 years after its founding. DAC is a vibrant community, with a good mix of old and new, of wisdom and challenge, committed to high quality education of yet another generation of engineers.

Despite continuous efforts to increase participation from industry, the majority of DAC members come from academia. The relationship between research and practice, however, is strong. Research conducted by DAC members has been enormously influential in how engineering is done today. Many of the dominant research topics three decades ago—such as simulation of dynamical mechanical systems, design optimization, structural design, computational geometry, or design for manufacturing—are now mature research areas. Industry has adopted the research results and created highly sophisticated commercial software systems that are routinely used in engineering practice, even taken for granted. DAC research has had a huge impact on how engineering is practiced today, and Papalambros predicts that the trend will repeat itself 40 years from now.

Papalambros also noted a qualitative difference in how the DAC community communicates research results that is not altogether desirable. In the past, papers presented research results with sufficient information to allow any other researcher to replicate the results if they wanted. This is no longer the case. Models and simulation software implementations are too complicated to report fully, publication space is too limited, and authors ponder the potential commercial value of their work too much, often encouraged to do so by their institutions. Whether these are real causes or not, the reality is that in most cases, the DAC community cannot replicate published results, contrary to a basic principle of scholarship. This situation is not unique to DAC. The DAC's 40th anniversary could be a good opportunity to examine how to reverse this trend.

DA was originally motivated by the advent of computational methods that allowed us to move tasks from humans to machines. Papalambros senses that our success in these efforts is now leading us to an almost reverse research direction: Bringing the humans back into a supposedly machine-dominated process. Many of the new research areas in design and DA seek to re-introduce humans explicitly in the design process. In a very real sense, DA has come full circle where humans and machines work together organically in an integrated, iterative manner, each performing the tasks that best suit them. This should come as no surprise. Humans have always built machines to augment their abilities and to free them for tasks of ever higher complexity and, frankly, more fun! And so, Papalambros is certainly optimistic about DAC's future.

Farrokh Mistree began his remarks by inviting the audience to join him in speculating about the future of DAC, so that 40 years from now (in 2054), another group of people can look back and celebrate what is yet to come. Mistree remarked that our enduring legacy is our archival publications and our students who enter the workforce. It is in the context of education that he suggested possible fruitful directions of research.

Mistree observed that current students face a different set of challenges in their careers than faced by earlier generations. Some trends are clear—while Moore's Law holds, computing will become more ubiquitous and less expensive. For design engineers this may well have two consequences:

(1) that complex engineered systems must be developed and deployed more rapidly with sustainability becoming increasingly important and
(2) that the availability of computational power will make the "process of design" faster and easier and that there will be increasing emphasis on problem identification, formulation and team work.

Mistree suggested that the DAC community has an opportunity to focus on the education of "Strategic Design Engineers"—engineers who are adept at conceiving and realizing "engineered complex systems" and balancing technical realization with sustainability and social responsibility [3]. Complex systems embody systemic features (emergent properties) that cannot be predicted or deduced. Hence, Strategic Design Engineers need to know how to account for emergent properties associated with the realization of a complex system. Mistree suggested that the key emergent properties are "complexity" and "uncertainty." It therefore follows that a Strategic Design Engineer needs to know how to identify and manage complexity *and* to identify and manage uncertainty.

The computing revolution continues to make processing cheaper and faster. Going forward, it is difficult to predict what tools will be available, but technological advancement will certainly continue. Hence, the question: "What additional career sustaining competencies do Strategic Design Engineers need to learn to have successful careers in realizing sustainable complex systems in a wireless, interconnected and democratized world?" Mistree offered the following meta-competencies for consideration [3]:

- Strategic Design Engineers need to be able to *speculate about the future* and tie the make-believe world of the future to the current world of reality. *Research:* What are the cognitive tools to accomplish this?
- Strategic Design Engineers need to be able *to continue to learn and be able to manage, organize, and learn from huge amounts of information*. *Research:* What curriculum, modes of delivery and evaluation are most appropriate?
- Strategic Design Engineers need to be able to ask questions. *Research:* How does an engineer identify a question worth investigating?
- Strategic Design Engineers need to be able to *recognize, understand, and manage emergent properties embodied in complex engineered systems*. *Research*: Specifically, how to manage dilemmas associated with the need for technological development, sustainability, and social responsibility?

Educating Strategic Design Engineers requires modifying how learning is facilitated and assessed. Learner-centric paradigms that are sensitive to different learning styles need to be explored, developed, tested, and adopted.

From Mistree's perspective, the DAC community's goal should be to educate engineers who are more than computational human–computer cyborgs content to solve interesting and complicated technical problems. They should be provided the opportunity to learn how to think through soft, subjective issues such as politics, political economy, and philosophy. They should also be able to speculate about the future. And in addition to learning how to absorb technical content, Strategic Design Engineers must be educated to identify and think through problems using the best tools at the time.

Mistree suggested that it is far more important to empower students to learn how to *adapt* than it is to *teach* them, as we do now in a typical undergraduate engineering program, how to solve problems however complicated. This change in focus necessitates a change in what we assess and how we do it. Some challenges include faculty assessment of the meta-competencies of learning how to learn, speculate about the future, and learn individually in a group setting.

Finally, Mistree challenged academics to encourage more of their best and brightest students to pursue careers in academia. This does not happen by chance. Faculty need to show by example that being a professor is the best job in the world!

4 New Perspectives on DA

In keeping with the theme established by the first three speakers—that of looking forward to the next forty years of DAC—six early career thought-leaders in the DAC community were invited to offer their own visions of the future of DAC research and education in a series of 5-min lightning talks.

Chris Williams from Virginia Tech opened the series of lightning talks with a topic that has been attracting significant attention in the design and manufacturing communities during the past few years: additive manufacturing (AM; often referred to as three-dimensional (3D) Printing). This technology's layer-by-layer approach effectively allows a designer to realize products of almost any geometric shape by selectively placing (multiple) material (s) on a point-by-point basis. The speaker claimed that with the maturation of AM, manufacturing is—perhaps for the first time—somewhat ahead of design. While conventional manufacturing technologies have often imposed significant constraints on designers, it is the lack of "design for AM" tools that is currently constraining the adoption and application of AM technologies. According to Williams, the DA community is well poised to address this research gap. Continued research into topology optimization, materials design and multi-objective optimization in the context of AM will enable the future hybrid design-AM engineer to realize products that achieve an ideal compromise for multiple objectives across multiple functions. Such research advances will empower the entire broad user base of AM: from the at-home designers who need tools to support cocreation and codesign, to the engineers working on industrial-scale machines and desire optimized structures. AM presents a tremendous opportunity for all design researchers; it will require collective expertise to help it achieve its true potential.

Rahul Rai from SUNY Buffalo took the podium next and addressed the need for suitable methods to support ideation activities and natural interactions directly in 3D modeling software. His talk discussed novel computational methods and associated 3D modeling software that can assist designers during ideation activities. Rai argued that the technology push that drives the integration of natural and intuitive sensors into everyday consumer devices such as Kinect (hand gesture) in our homes, "Siri" (speech recognition) in our phones and brain computer interfaces in commercial applications is setting the scene for the deployment of intuitive, natural and people–centric interfaces to support design creativity. Rai concluded with directions for potentially transformative research in 3D conceptual design exploration and ideation activities that can shift 3D model creation from an "art of the expert" to a "playground for the creative novice."

Purdue University's Jitesh Panchal continued the creativity-enabling theme arguing that developments in new web technologies and social media are resulting in a new paradigm of product realization where individuals self-organize into virtual communities to develop products. He mentioned examples of such virtual communities, which include open-source product developers, the maker movement, Enterprise 2.0 and others. He went on to describe how social collaboration coupled the rapid growth in 3D printing technologies and easy to use design tools and lowered the barrier to participation, thereby increasing the democratization of design innovation. He then cautioned that while self-organized communities have resulted in successful information-based products such as OPEN-SOURCE software and open encyclopedias, there are still fundamental barriers in extending these ideas to physical products. The emerging paradigms are accompanied with many open research issues related to how individuals participate in the design process, how designs are validated, how online security is achieved at various levels of product information, how incentives are aligned, how trust is established and how contributions of independent individuals on interdependent parts of a complex system are coordinated. Panchal concluded that these issues cannot be addressed by a merely technical view of design. Instead, he proposes a holistic sociotechnical view of design, and calls for the DA community to address these challenges.

The next lightning talk was given by Scott Ferguson of North Carolina State University, who reminded us that design-relevant user data spans a product's lifecycle, ranging from conceptual design to acquisition and end-of-life. Regardless of the source, interest in product user data has been focused on the common goal of improving product value by balancing information from the marketplace, the design firm and the end user. Ferguson added that while significant amounts of variety are possible for a consumer product, this variety must be strategically offered to meet various users, use cases and operating environments. Selected user comments were shown to demonstrate how opportunities for product improvements could be driven by the fusion of user data sources. The speaker believes that fusing various user data sources will create exciting research opportunities for the DA community and help maximize its broader impact. He closed by outlining the following research challenges: (i) better understand how such data should be captured, validated, and fused; (ii) pursue increased collaborations and interdisciplinary partnerships so that our focus can remain on using this data to improve design decisions; and (iii) demonstrate how this data can be used to enhance the user experience and verify that this data influences a product's success.

After the Midwest and the Southeast, it was the west coast's turn: Bryony DuPont from Oregon State University observed that the U.S. energy system is currently experiencing a period of immense change: as the country's population continues to grow and become more affluent, consumption of electricity continues to increase. By 2040, at least 16% of the U.S. power supply will be produced using renewable energy, totaling approximately 1250×10^9 kW h of electricity from wind, solar, hydropower, geothermal, and biomass. She therefore stressed that research in the area of design optimization for renewable energy systems is of paramount importance; not only will it help us to understand how best to incorporate new generation systems, but it will also contribute to advancing the existing system to be as efficient as possible. DuPont referred to wind energy systems optimization, which involves developing novel optimization methods and data-driven modeling to better predict wind farm power development, cost, and environmental impact prior to installation, as such an advance. In the coming decades we will face new challenges including understanding how emerging renewable energy technologies—such as wave and offshore wind power—can interface with the existing energy grid. Therefore, as she concluded, we will need to continue exploring how to optimize renewable and hybrid energy systems in terms of generation efficiency, reduction of emissions and water use and maintaining reasonable costs to the consumer, all while meeting the increasing demand for electricity.

The lightning talks concluded with the presentation of an innovative literature analysis tool developed in the lab of James Allison at the University of Illinois Urbana-Champaign with partial financial support from the ASME DED and the DAC. According to Allison, a body of research literature is not only a valuable archive of generated knowledge but also provides a means for quantitative analysis of a research community. Citation patterns between research articles and author collaborations each form types of literature networks, and rigorous network analysis techniques can reveal powerful insights into the nature of a research community (e.g., community structure, how a community generates and propagates knowledge and ideas, and how patterns of interaction evolve through time). Literature network analysis can also reveal important influences on a research community, and provide a more complete understanding of its impact on the broader scientific world. As the ASME DA community reflects on its past accomplishments and contemplates future directions, literature network analysis can serve a critical role in gaining a deeper understanding of these and other multidimensional issues. Allison demonstrated an initial version of an interactive web tool that can be used to visualize and analyze DA literature networks, including their evolution in time, identification of important articles and collaborations that form their backbone, clustering and subcommunity identification, and topic modeling. He hopes that insights gained through this investigation will generate opportunities for improvement and identification of new potential collaborations.

5 Concluding Remarks

In addition to the tremendous advances that have been made in the last four decades, there are clear indications that the future of DAC remains brighter than ever. If the 40th anniversary symposium speakers are as prescient as they are accomplished, several compelling research challenges are poised to drive the future of DAC. The DAC community is primed to effect profound changes in design pedagogy that could completely transform engineering education into a technology-enabled, personalized learning environment. DAC researchers are being challenged not only to develop more advanced computational methods that move design tasks from humans to machines but also to establish design tools that allow humans and computers to work together in an integrated way, leveraging their respective strengths. Rapid advances in all areas of DA—representation, optimization, evaluation, integration—are being applied to some of the most important engineering challenges of the 21st century, including design of sustainable engineered systems and products that truly leverage the capabilities of AM. Engineering designers are making increasing use of big data for designing smart, customizable products, and in the near future, much of the design process may be conducted by virtual communities that were unfathomable at the dawn of the DAC. Even the everyday tools used by design engineers are evolving rapidly as computational tools become more powerful and realistic, yet less expensive and more ubiquitous, and interactive, immersive design systems become more commonplace in a world that was once governed solely by the keyboard and mouse. Above all, the DA community continues to strive to embody, in the words of Papalambros, a rich mix of old and new, of wisdom and challenge, committed to the high quality education of yet another generation of engineers.

References

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