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**DTM PAST, PRESENT, AND FUTURE: REFLECTIONS ON AND BY THE DESIGN
THEORY AND METHODOLOGY RESEARCH COMMUNITY**

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ABSTRACT

This paper describes the results of an agenda-setting panel session that took place at the 2021 International Design Engineering Technical Conferences organized by the Design Theory and Methodology (DTM) research community. While the state of design research in engineering design has advanced tremendously in the last thirty-five years since the formation of the DTM community, reflecting on the successes and challenges faced by this community revealed several key directions and opportunities that this community is well positioned to take. Namely, panelists and audience members in the session identified five new agenda items that have the potential to further strengthen research on Design Theory and Methodology: 1) Ethics, Equity, and Justice-focused design research, 2) Design for Sustainability research programs, and 3) Research on Computational Agents as team members in the design process, 4) Building new theories from research conducted on Design Theory and Methodology, and 5) Focus on inclusive excellence in the review process of new and cross-disciplinary research. These agenda items as well as reflections on the history and

legacy of the Design Theory and Methodology research community on the evolution of design research more broadly are discussed in this paper. The results of the panel session provide directions for next-generation design theory and methodology research that is effective, inclusive, and impactful.

Keywords: Design Theory and Methodology, Agenda-setting, Reflection, Design Research, Panel session.

1. REFLECTIVE AGENDA SETTING

The Design Theory and Methodology (DTM) research community has evolved tremendously in the last thirty-five years since its founding in 1988. Researchers in our community continue to grow out of a wide range of disciplines (e.g., Mechanical Engineering, Industrial Engineering, Computer Science, Psychology), adding to the richness and diversity of the work conducted in this space. Our success as a community contrasts the challenges that our founders faced, as they struggled to find legitimacy in engineering and scientific communities at a time when design research was perceived to

lack rigor, and explored concepts that were deemed at the time by some to be irrelevant to engineering research. The importance of design is now acknowledged at all levels of engineering education [1], and engineering designers are now called upon to address the most important challenges in society [2]. Coupled with this increasing demand for engineering design expertise, the growth of this research community has led to the development of new topics and interest areas that are now considered part of the “canon” of Design Theory and Methodology: Ideation and Creativity (see for example [3,4]), Design Cognition (see for example [5,6]), Design Neurocognition (see for example [7,8]), Design Automation [9–11], Design for Sustainability (see for example [12–14]), Teaming in Design (see for example [15–17]), and Prototyping and Representation (see for example [18,19]). These and other new and evolving areas of inquiry have significantly expanded our understanding of design research, and have added new methods, theories, and approaches to the repertoire of our research community.

While these advances have benefitted our community, critical reflection [20] on our progress thus far and on our intentions for the future is crucial for ensuring the health and growth of our research community. Taking a page Schön’s theory of Reflective Practice in design, our ability to reflect continuously on the actions that have been taken, critically analyze the effects of these actions, and develop insights about the values that drive these actions is key to effective learning and professional growth [21]. By setting intention for the type of community we wish to become, the type of research we aim to pursue, and the values that we want to uphold, we can use the collective strength of our research community to continue to make an impact on design research as a discipline. Thus, this paper reports the result of a panel session that was held at the 2021 International Design Engineering Technical Conferences that focused on identifying and exploring our community’s past progress, in order to develop an agenda for research in the future. The panel was conducted virtually over Zoom, and consisted of all past DTM Award and DTM Young Investigator Award winners (the second through eighth authors on this paper).

The panelists were posed a set of 4 questions prior to the panel session, and were each given five minutes to respond to 1 or 2 of the questions during the remarks:

1. What are major accomplishments of the DTM community to date? Think of particular theories or methodologies we have developed and what kind of impact have they had on our research?
2. What are the strengths of the DTM community? Are these strengths unique to our community? Do other communities share them?
3. What are the challenges we face in the DTM community? Are these challenges unique to our community? Do other communities share them?
4. What is the future of DTM research? Where do you see our community contributing in the future and where should we focus our efforts?

Once each panelist had completed their brief remarks, the session was then opened up to questions and comments from the audience in attendance. The majority of audience members were regular members of the DTM community, and consisted of faculty at institutions of higher learning, graduate students in related programs (e.g., Mechanical Engineering, Industrial Engineering, Engineering Design) and community partners from industry and government agencies. These comments and questions built on the panelists’ individual remarks, and together, form the basis for the themes presented in the following sections. The remainder of this paper is organized as follows: First, we present the impact and legacy that the DTM research community has made in the larger design research space, then the strengths and challenges that face this community are explored. Lastly, new research directions are identified as priorities for this community, and strategies for strengthening design research in our community are explored.

2. IMPACT AND LEGACY OF DTM RESEARCH

From the origins of Design Theory and Methodology as a subfield within Engineering Design, the effect of this community on design research is wide-ranging. At a time when design research was largely conducted on an ad-hoc basis, with minimal efforts to advance the science of how we understand human behavior in design, the early Design Theory and Methodology researchers sought to understand problems that were deemed unimportant by major publication venues and granting agencies. Concepts such as creativity, design process, and decision-making under uncertainty were viewed by these early researchers as crucial in building a deep understanding of the science of design (see for example [22,23]), but were often considered beyond the scope of mainstream engineering design research. In addition, many researchers in these early years worked to add rigor to the practice of many stages of the design process, such as customer needs assessment, idea generation, concept selection, and prototyping (see for example [24]). Researchers who shared this common passion for design research collectively launched the first Design Theory and Methodology conference at IDETC in 1989, with the following session titles: Design Process Evaluation, Knowledge Representation and the Design Process, and Employing Computation in Design. Since then, the conference has grown to accommodate the larger community, varied interests and expertise, and has responded to current national and global needs.

There are numerous examples of highly influential contributions to design methods and practice that find roots in our community, such as John Hirschrick’s interest and involvement in next-generation Computer Aided Design (CAD) tools through the development of Solidworks, which went on to help democratize access to these powerful engineering design tools and has shaped the industry in significant ways. Other influential products of this community include Karl Ulrich and Steve Eppinger’s seminal book on Product Design and Development [25] that is now used as the nominal introductory design textbook in many engineering schools. Numerous other high-impact methods and approaches for design that found root

in the DTM community include Set-based Design [26], Agent-based Design [27], the Design Structure Matrix [28], Axiomatic Design [29], Decision-based Design [30], Grammar-based Design [31], and the Functional Basis of design [32], to name a few. So then, why does the impact of our work remain largely invisible? While these contributions have certainly changed the course of design research and practice for decades, the influence of the DTM community behind these contributions have remained relatively obscured. This is in part due to the lack of a clear and traceable account of discussions and conversations that took place during annual DTM meetings, and the “export” of these ideas outside of the DTM community to disciplines such as Marketing and Engineering Management.

Another major impact of research conducted in this community is on the Engineering Education field. A considerable number of researchers in this space have made significant contributions to how design is taught in education systems, transforming the way that educators approached design as a single event that occurred during development, to a process that can be systematic, intentional, and structured [33]. This legacy has made design more accessible as a profession to more students, and regularized design approaches, methods, and tools across curriculums and disciplines. Advances in the way that we teach engineering to students has far reaching consequences, from the tools that are brought with these students into industry, to the increased interest in design as a career. Design skills such as analytical thinking and innovation, complex problem-solving, and creativity, originality, and initiative are now listed as the most in-demand skills in technical industries across the globe [34], in part because design research has highlighted the value of these modes of thinking for tackling large, unstructured, and wicked problems.

3. STRENGTHS OF THE DTM RESEARCH COMMUNITY

The impact of this community on design research as highlighted in the previous section can be attributed to the many strengths of our community that the panel reflected on during the session. First, since the research being conducted in this space is highly interdisciplinary, the researchers doing the work in turn come from very broad and diverse backgrounds and training. While the early DTM research community grew out of the Engineering discipline, the composition of the researchers in this space has grown more diverse in recent years. Researchers with backgrounds in Computer Science, Neuroscience, Anthropology, Psychology, Economics, and Information Science are now also part of important discussions within our community and find ways to meaningfully contribute to design research in this space. Simply put, DTM sits at an “interdisciplinary crossroads”; much of the work in this space draws on knowledge from multiple disciplines, and these disparate schools of thought converge at one of the most crucial areas of inquiry in modern engineering, sought after for its power to tackle the large and important problems of our generation.

This diversity of thought and training has laid the groundwork for the increased reliance on research methods from

the social sciences, such as ethnography, grounded theory, and protocol analysis (see for example [35–38]). In contrast to all other engineering disciplines, DTM research increasingly values these methods for their ability to describe human behavior, cognition, and experiences, since these concepts are central to the human endeavor that is design. This expansion of research methods has influenced the different units of analysis studied in design research, from protocol studies to investigate individual expert designers’ cognition *in situ* [39], to ethnographic observations of teams of designers in communication with one another [36], to explorations of how concepts such as identity, culture, and engineering intersect in Makerspaces [38]. These methods equip the researchers with the tools needed to understand the complex systems and interactions that occur in design.

The last strength of the DTM community that was discussed by the panelists was the culture of collegiality, openness, and transparency that has been cultivated over the years. While this research community is relatively small, the number of women and people of color who have taken on leadership roles in the community has increased rapidly in the last decade. Relative to other engineering disciplines, we tend to attract a more diverse set of students and practitioners in part due to the interdisciplinary nature of the work and the focus on community building that has been a priority of the leadership. In addition, the influx of new and emerging researchers in our field allows for healthy growth of the community and transfer of new ideas and approaches.

4. CHALLENGES FACING THE DTM RESEARCH COMMUNITY

While the previous section illustrates the strengths of this unique research community, the panelists also reflected on several challenges currently facing this community. Many of these challenges stem from the size, nature, and age of the community, and are counterparts of the strengths discussed in the previous section.

First, as a likely byproduct of the complex nature of the design process in practice, it can be a challenge to conduct and report research findings in a manner that is actionable and useful for design practice. Much of the research presented at DTM tends to be highly specific to a limited set of contexts in an effort to increase the internal validity of our findings. The consequence of this highly localized and context-specific research is the lack of generalizability of the findings to other areas of design practice. Indeed, a finding specific to first-year engineering design students at a large public university is often difficult to apply to a small design firm where team members have decades of experience in their respective design disciplines. While this response to the complexity of the design process allows us to develop and conduct highly controlled studies in a particular context, design is, by nature, an actionable human activity, and the work conducted in DTM should impact future research or practice in meaningful ways.

Related to this challenge, is the fact that it is, and has always been, very difficult to recruit study participants that are expert

designers in industry. Since much of the work conducted in this area directly impacts practicing designers, it is important that these designers are included in the research process, either as stakeholders in research designs, or as participants in field or laboratory studies. However, a large majority of work presented in this community uses engineering students as participants for studies. While research on engineering education and engineering student learning is important, there is a gap in understanding how these findings translate to engineering industry, where a complex web of constraints, motivations, and organizational factors can influence how phenomena of interest are expressed.

Another challenge noted by the members of the panel was the abundance of empirical results from studies conducted by members of the community, without an equal emphasis on building theory from these results. As a consequence, DTM on paper appears to be “result rich, and theory poor”. In other words, since researchers come from many different disciplines and collaborate with researchers from other disciplines, there is a tendency to “import” theories from these disciplines and apply them to empirical results in the context of engineering design. This leads to our work becoming “theory laden”, where the observations that are made become highly dependent on the theories that were the foundation of specific study [40]. This challenge can affect the impact and reach of the research conducted by this community, since it can be difficult to apply the findings to different application areas. Indeed, visibility of the DTM community is limited in other fields, even if members of our community collaborate heavily with researchers in these other fields. In other words, the transfer of knowledge and application of theory appears to occur in a single direction (from other disciplines into DTM), as opposed to a more dynamic and symbiotic relationship where knowledge is built collaboratively between disciplines and findings make their way across disciplinary borders in both directions. This challenge is further compounded by the tendency of members of the community to cite concepts from other disciplines in publications, as opposed to focusing on existing concepts within the community, thereby strengthening the research conducted within the DTM space.

The last challenge discussed by panelists in this session was related to the size and scale of the community itself. While the close-knit and collegial nature of the community creates a healthy scholarly environment for scholars in our space to grow, this can also be exclusionary as researchers from outside the community attempt to gain traction in our field. More data is needed to understand the impact of the community culture on paper acceptance and rejection statistics, but the impact of how our community operates must be investigated. Much in the same way that the first DTM conference was started by engineering design researchers seeking a “disciplinary home”, so too must the current DTM community welcome scholars from other core spaces into this interdisciplinary space. Rethinking the boundaries of what defines Design, Theory, and Methodology research is a task that falls to the future leadership of this

community and its members and is vital to the survival of this important research community.

5. THE FUTURE OF DTM RESEARCH

In response to the challenges outlined in the previous section, several key future research directions were identified by members of the panel. These specific agenda items are critical to addressing important challenges facing our society, and are aimed at shaping the DTM community in positive ways.

First, there is a real need for design researchers to integrate topics related to ethics, equity, and justice in all aspects of the research that we do. From the study development phases of research, to the dissemination of results, to the application of new design methods in practice, we are called on to intentionally focus on how these actions and decisions impact users, the community we serve, and society at a broader scale. No longer can designers and engineers remain blind to the cascading impact of our work. Questions such as how to incorporate the ethics of autonomy, respect for persons, privacy, and inclusive design into the research that we conduct are central to this agenda item. As design researchers, we are well positioned to exercise our power as one of the most influential forces in decisions that shape our world, and we bear a responsibility to proactively consider the ethics of the artifacts, processes, and systems that we design. Developmental work is already ongoing to integrate ethics into design research and education [41–43], but more work is needed to give voice to this movement and regularize discussions about ethics into every aspect of research conducted in DTM. Key opportunities that were identified by panelists in this agenda item are the following:

- Critical analysis of the ways that current engineering design practice disaccommodates or excludes individuals from marginalized communities (e.g., older adults, people with disabilities).
- Thoughtful development and critique of Artificial Intelligence in engineering design and the impact of these new technologies on the stakeholders of a system.
- Integration of ethical theories such as utilitarianism, virtue ethics, or deontology into design decision-making research and support tools.
- Reexamination of the set of virtues required of professional engineers and operationalization of the virtues in practice.
- Involvement of end user communities in the design and development process in engineering (e.g., participatory design) to rebalance power in designer-user relationships.
- Development of new design tools, methods, and approaches that center design justice and ethics from the start of the design process.

The second key agenda item that falls to our community is the need for more targeted and effective approaches to design for sustainability. Long has this wicked problem held the interest of researchers in DTM, in part due to the importance of the issue, but also because design researchers are well positioned to tackle

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