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**GUEST EDITORIAL**

# Sketching and pen-based design interaction

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## 1. INTRODUCTION

Sketching has long been an essential medium of design cognition, recognized for its ability to fluidly represent design concepts across a range of formality and styles. Likewise, digital tools to support the needs of designers as they sketch have steadily become both more sophisticated and more prominent in design practice. This Special Issue aims to bring together work in these two areas and considers what, how, and why designers sketch in the context of recent developments in paradigms and tools that facilitate sketch activity.

The resulting seven papers featured in this Special Issue provide insights on the role of sketching in design and present new computational technologies that advance the boundaries of sketch-based design tools. Although the initial solicitation did not specifically call for it, this Special Issue suitably consists of papers that are either cognitively or computationally oriented. As such, we have found this categorization best reflects the structure of this Special Issue. Thanks to the variety of research challenges undertaken and the diversity of the domains explored, we believe this Special Issue caters to a broad audience with different backgrounds and interests. Those who have even a casual interest in sketching and design will find the results of the cognitively oriented papers compelling and thought provoking, whereas the technological advances demonstrated in the computational papers will hopefully be inspiring. Those who have more familiarity with the topics may gain new insights into the field, while better recognizing the opportunities and challenges of integrating digital pen technology into design-oriented tasks. Collectively, the papers included in this Special Issue shed light on the unique relationships among sketching, creativity, and digital design technology, from which valuable lessons are learned and future projections are made.

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## 2. SOLICITED TOPICS

The goal of this *AI EDAM* Special Issue was to collect recent research in a number of design-related topics, including knowledge representation, capture, and reuse in sketching; the role of sketching in design, creativity, problem solving, and cognition; sketch-based generative design; sketching in collaborative design; sketching and aesthetics; sketch recognition; sketch-based computer-aided design (CAD) and solid modeling; novel sketch interfaces, visualization, and implications; and applications in engineering, computer graphics, art, architecture, and medicine.

## 3. PAPERS IN THIS ISSUE

The papers that appear in this Special Issue fall into two distinct categories of exploration. In the first group are the *cognitively* oriented papers (labeled cognitive) that investigate how designers sketch in a variety of education and professional settings. In the second group are the *computationally* oriented papers (labeled computational) that study how digital sketching tools can more effectively support the work of sketching. Several papers weave together elements of both sketch cognition and digital tool development, and they are noted with a hybrid label of cognitive/computational.

"Sketching Across Design Domains: Roles and Formalities" (cognitive) reviews a deep and rich literature on the types and properties of sketches across activities from idea generation, communication of design ideas, and reasoning about a design. It includes studies of designers from domains as diverse as mechanical and structural engineering, architecture, planning, graphic design, knitwear design, and software development. The study discusses the dimensions of formality in sketches: intention, appearance, description, and interpretation. Chief among the findings of this work is that a designer may modulate the formality of sketches to suit particular roles throughout the design process, suggesting that even more nuanced ways of thinking about formality should be considered in future research.

"The Influence of Sketch Quality on Perception of Product-Idea Quality" (cognitive) investigates the links between the quality of a sketch and the perception of the creativity of the idea represented in that sketch. Products were sketched by individuals of varying levels of sketching skill, and the sketches themselves exhibited differing levels of detail. These sketches were then assessed by 360 individuals as to their creativity. It was found that the highest quality sketches, as assessed by the realism of their line work, perspective, and proportions, were more likely to be rated as most creative whereas lower quality sketches were linked to lower creativity rank. In other words, the presentation of an idea through sketches may be critical in the evaluation of its creativity. Well-executed sketches may enhance the perception of creativity whereas poorly rendered sketches may cause a creative idea to be overlooked.

"Sketch-Based Interfaces for Modeling and Users' Needs: Redefining Connections" (cognitive/computational) takes a designer-centered approach to developing sketch support systems. It examines how architects and product designers perceive and reinterpret sketches and how those perceptions may differ from current paradigms for design support tools. First, it finds that designers sometimes interpret architectural sketches by geographical zones as well as by more traditional architectural symbols in a sketch, and this zonal interpretation strategy may have implications for sketch support in architecture in particular. Second, the paper considers the ambiguity of lines in product design sketches and observes that designers often create strokes on top of each other as part of the process of thinking about a design, starting with a rough line and gradually crystallizing. This suggests that the immediate, automatic beautification of lines prevalent in sketch support systems may interfere with a designer's ability to think about a design through the act of sketching. Third, the paper examines the way designers switch between sections, elevations, and perspectives during sketching and how these aspects of sketching support ideation. These findings counter the notion that three-dimensional models should always be automatically generated from two-dimensional sketches, but should rather be interactively supported.

If we believe that sketching and the use of digital tools to support sketching are of value to design, it is instructive to assess the value of sketch training in undergraduate education curriculum. "Research on Encouraging Sketching in Engineering Design" (cognitive/computational) finds that sketching behaviors and sketching frequencies of engineering students can be influenced by sketching assignments and lectures on the importance of sketching. In particular, a series of experiments are conducted that show, without proper instruction, engineering students typically lack an understanding of sketching and its importance in design. However, this behavior can also be reversed through carefully designed assignments and instructions, complemented with digital sketching technologies.

The paper "Computer-Aided Design Versus Sketching: An Exploratory Case Study" (cognitive/computational) makes the observation that student designers are entering the workforce immersed in digital tools for supporting design, particularly CAD. The paper includes a case study of how and why a student design team used sketching and CAD tools, and it further notes the results of interviews with both novices and experts on their perceived value of sketching and CAD. It is interesting that a disconnect was found between novice and experienced user groups in the perceived capability of CAD tools. Moreover, opinions on the importance of freehand sketching skills differed widely between novice educators and novice industry professionals, suggesting that there is a significant change in beliefs as to the importance of sketching when recent graduates transition from academia to industry.

"Sketch-Based Shape Exploration Using Multiscale Free-Form Surface Editing" (computational) explores the use of digital sketching for three-dimensional shape modeling and its use as a design exploration tool. The paper presents a method for designers to *decompose* existing designs into different levels of shape details and make sketch-based modifications to any desired level. The authors demonstrate that the ability to decompose and independently modify a design in different geometric detail levels and later resynthesize the results allows sketch-based shape exploration to be used much more effectively compared to previous approaches. Analogous to isolating and independently manipulating the vibratory mode shapes of a structure, the proposed approach allows designers to fluidly specify the level of geometric manipulations they intend to execute, thereby preserving all other aspects of the design intact. Once the modifications are complete, the results are automatically integrated into the final design. This allows designers to sketch large-scale structural modifications and explore the resulting alternatives, just as easily as they would sketch the new shape of a small, texturelike detail on a surface. The paper demonstrates this technique on several industrial design scenarios.

Sketch recognition in various forms has gained considerable attention in the last few years as a means to support engineering and design tasks. In symbol and gesture recognition, in particular, a large group of researchers have generated a multitude of algorithms, standards, and valuable data sets. However, most approaches to date have focused on carefully designed recognition algorithms that aim to maximize the performance within the context of interest. The paper "RATA.Gesture: A Gesture Recognizer Developed Using Data Mining" (computational) takes a different approach to this problem. It evaluates a wide range of data-driven algorithms developed for digital ink recognition. Specifically, it examines a variety of algorithms focusing on the use of attribute selection and ensemble strategies using a rich feature set. The paper demonstrates an ensemble of a few select algorithms to be more flexible and accurate on average than all other algorithms tested. In addition, the results provide some benchmarks against which future algorithms can be measured.

## 4. CONCLUSION

This Special Issue offers several thought-provoking viewpoints on the value of sketching in design and advancements in the tools to facilitate sketch creation. These perspectives can serve as a valuable starting point for further scholarly research in these areas. We foresee that interest in sketching and sketch tools will continue to grow and influence how design teams go about the process of creating innovative products and systems in the future.

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