Guest Editorial: Innovation in Design Processes

I. Innovation in Design Processes

DESIGN is the human process of applying knowledge to create novel and useful artefacts, such as new products, services, and systems with economic and societal values [29], [21], [16]). In practice and literature, the relevant terms and definitions are often blurred. The design process is often referred to as the "new product development" process [30], "innovation process" [31], "design innovation" process [13], etc. Not all design processes lead to inventions or innovations. The design processes that yield innovation are often coupled with the scientific research process and the entrepreneurship process [17].

Herein our focus is *not* on the innovation arising from the design process, but on the innovations in and of a design process itself that can increase innovation success from the design process. "Design process" is an elusive concept. It can be described at different levels of abstraction [28], and the same process can be interpreted in different ways [24]. Often it is conceptualized as a series or stages of activities, such as need finding, requirement elicitation, conceptual design, embodiment and detailed design, prototyping, testing, and deployment [32], [3], [7]). These design process activities can be supported by formal design methodologies and tools, such as TRIZ [1], design-by-analogy [9], design structure matrix [4], and infused design [33].

Over the past decade, we have been witnessing a surge of new design process paradigms (see Fig. 1), such as design thinking [3], lean startup process [23], the united innovation process that integrates science and entrepreneurship with design [17], crowd intelligence [2], [A3], data-driven design [13], [14] or data-driven innovation processes [20], as well as the design innovation process that integrates design thinking with system thinking [26].

These new paradigms are *de facto* innovations in or of the design processes. They provide new insights and new ways of working for some but not all design processes [11]. Their emergence has been largely driven by the rising complexity and uncertainty in contemporary design processes, the advances of digitalization, data science, artificial intelligence, and technologies in general, and the growing needs for human-centered innovations by design to solve many new grand challenges to the human society [10].

The technological products, systems, and services that we design and use today are increasingly complex and interlinked [6]. In response, the design processes are also involving larger multidisciplinary teams and more dispersed collaboration, and integrating more diverse prior knowledge, technologies, and legacy systems [18]. The R&D organizations, development processes, and supply chains of many products have become truly dispersed with diverse stakeholders in complex systems and ecosystems [15], [5]. In turn, the growing complexity of the products, processes, organizations, and stakeholder ecosystems give rise to the uncertainty facing designers and managers in the design processes. Such trends heighten the need for new methods, tools, and support systems to coordinate design activities and to plan, structure, and manage the design processes [25], [8], [27], [4], [12], i.e., the innovation in the design process.

This special issue aims to explore the emerging and innovative concepts, methodologies, tools, and strategies for structuring, managing, and planning design processes. Table I lists the collection of ten papers in the special issue with their titles and topic/method/data tags. The collection of papers in the special issue emerged naturally to cover some of the cutting-edge design process paradigms in the design research and practice communities (see Fig. 1). The authors approach design from different disciplinary backgrounds coming from engineering design, system engineering, computer science, and business management. In the following, we provide a detailed review and synthesis of the papers included in the special issue.

II. Innovations in Design Processes in the Special Issue

Design thinking, which emphasizes empathy and need finding for designing products and services that people want, proliferated in the design innovation practices over the past decade. The design thinking process contrasts with the technology-push process that starts with a technological breakthrough and then takes it to the market. Our special issue includes two papers on design thinking. de Paula *et al.* [A1] addressed the adoption and implementation of designing thinking in the new product development processes of companies, whereas Przybilla *et al.* [A2] examined the applicability of design thinking for digital innovation.

To identify the factors that affect the effective integration of design thinking in new product development processes in organizations, de Paula *et al.* [A1] conducted a systematic review of the design thinking research in the new product development literature in the past two decades. Via literature survey and synthesis, they specify the factors that company leaders and managers should consider for their design thinking initiatives for new product development and innovation. They also propose the directions for future research and practice of design thinking in new product development.

To address the shifting locus of innovation from physical to digital technologies, Przybilla *et al.* [A2] examined the applicability of design thinking for digital innovation. They selected two opposing (mechatronic versus digital) examples from 21 design thinking projects to compare and identify critical incidents as opportunities and challenges of applying design thinking. In the fully digital context, they observed opportunities in improved need finding and the ability to offer individualized products, and uncovered difficulties in imagining digital features, estimating their feasibility, and correctly setting the fidelity of prototypes.

In design practice for innovation, crowdsourcing is another growing approach to seek diverse design ideas or solutions,

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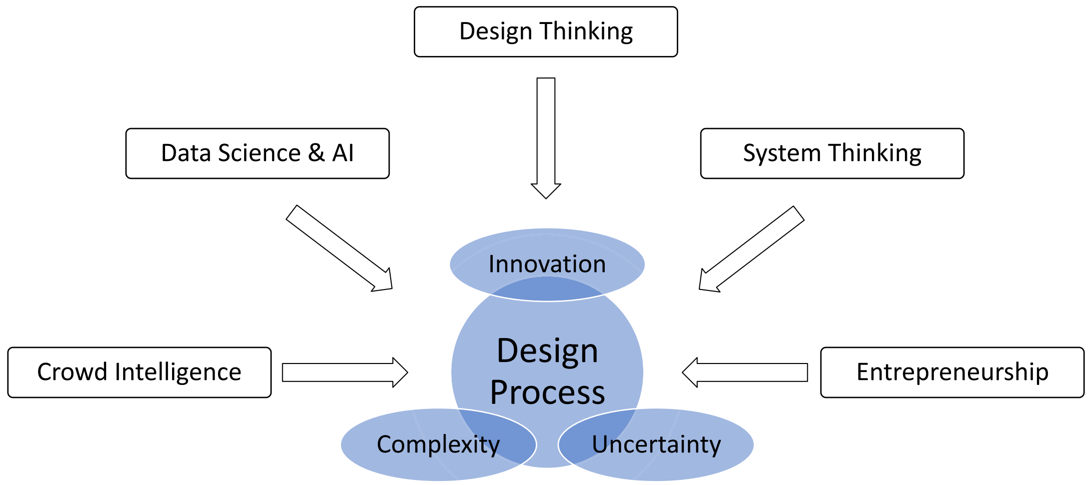

Fig. 1. Latest innovations in design processes.

reduce development cost, and time, and engage consumers from the crowd, often online. Despite its promises to innovation, crowdsourcing initiatives in practice are prone to failures, and their effectiveness is affected by a few factors, such as the domain knowledge of the crowd participants, problem complexity, and incentive structures. Crowdsourcing initiatives as part of the design process also need to be systematically designed. Our special issue includes two papers that seek to better understand crowdfunding to guide the design of crowdfunding initiatives as part of design processes for innovation.

Shergadwala *et al.* [A7] adopted a framework that considers a sequence of decisions in designing crowdsourcing initiatives of different kinds and used it as the guide to conduct structured interviews with four industry professionals on the benefits and the challenges experienced by them for implementing crowdsourcing initiatives in engineering design projects. Based on the findings from the interviews with practitioners, they proposed a set of research opportunities, with regards to the design of crowdsourcing initiatives for engineering design.

To answer the specific question of whom in the crowd are willing and capable to contribute appropriate solutions to complex engineering design problems for the prospect of a prize, Szajnfarber *et al.* [A8] analyzed data from a unique field experiment. They found that the good solutions came from solvers with prior within-discipline experience, and of those, more of the good solutions came from solvers who perceive their expertise to be adjacent to the problem. They also found evidence for the role of crowdsourced submissions in augmenting concept generation and trade space exploration in the design process.

As another crowd-based approach, online reward-based crowdfunding campaigns (i.e., pledging a crowd of backers to preorder online the first batch of novel products as rewards) have been growing adopted (by mostly startups and small design teams) to validate demands for novel design concepts, discover early adopters for innovative designs, and seeking learning and feedback from early adopters to guide design changes and improvements. It is an entrepreneurial approach to implement design thinking by discovering and empathizing with early adopters and to implement the lean startup methodology by engaging "paying users" of minimum viable products for validated learning about the design, with the crowd over the Internet. The value of online reward-based crowdfunding campaigns for informing design is less recognized than that of online crowdsourcing, and less recognized than its other value for financing design and production.

To inform design, the crowd-based crowdfunding campaigns must succeed first by attracting a crowd of early adopters online. However, crowdfunding campaigns of novel designs are naturally faced with high uncertainty and suffer low rates of success to discover and engage enough early adopters. To guide design innovators for effective crowdfunding campaigns, Song *et al.* [A3] presented a data-driven methodology to build a prediction model with critical factors for crowdfunding success, based on prior online crowdfunding campaign data. The critical factors can guide future campaign developments, and the prediction model may evaluate crowdfunding potential of creative design projects in context, to increase the chance of crowdfunding success for design innovation.

While online crowdfunding platforms provide data on early-stage innovative designs and early adopters' preferences, e-commerce websites also accumulate massive data of the specifications of mature products and customers reviews. Properly mining and relating the customer opinions to product specifications may guide the design of products with features and specifications that customers want. However, there is a semantic gap between customers that normally express their needs in layman's terms online and designers that define product specifications with technical terms and design domain knowledge.

To address the semantic gap between product specifications and customer comments, Wang *et al.* [A9] crawled the product reviews from the customers and corresponding product specification data from e-commerce websites and use such data to train a neural network that can map natural language product reviews of customers to product design specifications. The deep learning model is expected to automatically translate the expressed needs of customers in natural language of layman's terms to technical design specifications and thus make the product design decisions more informed.

Design thinking, lean startup, online crowdsourcing or crowdfunding campaigns, and customer opinion mining address the

TABLE I
TOPICS OF THE PAPERS INCLUDED IN THE SPECIAL ISSUE

Authors	Titles	Tags
de Paula *et al.* [29]	From acquaintances to partners in innovation: an analysis of twenty years of design thinking's contribution to new product development	Design Thinking, Product Development, Literature Survey
Przybilla *et al.* [30]	Design thinking in digital innovation projects – Exploring the effects of intangibility	Design Thinking, Digital Innovation, Case Study
Shergadwala *et al.* [35]	Challenges and research directions in crowdsourcing for engineering design: An interview study with industry professionals	Crowdsourcing, Engineering Design, Interviews
Szajnfarber *et al.* [36]	Who is in the crowd? Characterizing the capabilities of prize competition competitors	Crowdsourcing, Complex Problem, Domain Knowledge, Field Experiment
Song *et al.* [31]	Crowdfunding for design innovation: Prediction model with critical factors	Crowdfunding, Design Innovation, Entrepreneurship, Data-Driven
Wang *et al.* [37]	Bridging the semantic gap between customer needs and design specifications using user-generated content	Customer Reviews, Product Specifications, E-commerce Sites, Deep Learning
Kreye *et al.* [32]	Dynamism in complex engineering: explaining uncertainty growth through uncertainty masking	Uncertainty Type, Design Stages, Email Data
Maruster and Alblas [33]	Tailoring the engineering design process through data and process mining	Design Change, Process Mining, Event Log Data
Panarotto *et al.* [38]	Value-based development connecting engineering and business: a case on electric space propulsion	Engineering-Business Communication, Value-Driven Design, Functional Requirements
Liu *et al.* [34]	Assessing suppliers for complex products from the perspective of power	Uncertainty, Supplier, Malleability, Flexibility, Power

uncertainty associated with the latent needs, demands, and preferences of customers and users to make design more informed. Meanwhile, there is also uncertainty within the complex design processes that involve different stakeholders for different activities across various stages. Such process and stakeholder uncertainties are particularly high and dynamic in large, complex, and innovative engineering design projects, and need to be properly recognized, monitored, analyzed, and managed to ensure the effectiveness of the design processes.

Kreye *et al.* [A4] uncovered how different types of uncertainty (e.g., technical uncertainty, organizational uncertainty, relational uncertainty, and resource uncertainty) evolve throughout the design process, by analyzing the content of over 54 000 e-mails in the conceptual design, detail design, system integration, and construction phases of a renewable energy power plant. They identified a new mechanism, namely "uncertainty masking," as a process through which a root uncertainty results in a symptomatic uncertainty and then root and symptomatic uncertainties compound to hamper uncertainty resolution and increase uncertainty during later stages. Such data-driven understanding, in turn, can guide better management of different types of uncertainty across design stages.

Maruster and Alblas [A5] addressed the uncertainty specifically in the design change process via process mining. Engineering design changes are constantly required to address the changing market demands, governmental regulations, and competitive needs. However, the complexity and ambiguity of the engineering change processes often challenges the management of them. To address this complexity, Maruster and Alblas [A5] proposed a data-driven approach, based on process data mining techniques and text analytics, for automatic extraction of the unstructured event logs, descriptive, diagnostic, and predictive analytics of the engineering change processes. The proposed data-driven process mining and analysis approach may inform better design and management of the design change processes.

Panarotto *et al.* [A10] addressed the uncertainty arising from the misalignment of goals and incentives and the lack of common understanding of engineers and business managers as internal stakeholders of a design process. Business managers normally focus on financial values of innovation, whereas engineering design teams focus on product functionality and technical requirements. Collopy *et al.* [5] proposed a methodology, based on value and functional modelling, to facilitate the communication between business decision makers and engineering design teams to work more tightly together to explore technological options on business scenarios. The implementation of the methodology in a practical design project on new satellite propulsion technologies provided some evidence of its benefits in terms of increased iterations, improved quality, and reduced risks of technology integration.

Liu *et al.* [A6] focused on the uncertainty associated with suppliers. For design innovation, companies need suppliers that are malleable to their changing needs in the dynamic product design processes. To assess and select malleable suppliers, Liu *et al.* [A6] unpacks the malleability concept into supplier's flexibility and relative buyer–supplier power and proposes a decision tool that combines the assessments of power and flexibility to provide a malleability index. They use an empirical case study with a leading European engineering company to illustrate the value of the tool and the indicators for more informed selection of malleable suppliers for design innovation projects.

III. Synthesis

The papers in this special issue make important contributions to studying and supporting the trending innovations in the design processes as we observed in the design practice (see Fig. 1) and offer a broad range of topics and discussions (see Table I).

The special issue includes two papers on design thinking (de Paula *et al.* [A1], Przybilla *et al.* [A2]), two papers on crowdfunding (Shergadwala *et al.* [A7], Szajnfarber *et al.* [A8]), one paper on crowdfunding (Song *et al.* [A3]), one paper on online customer review mining (Wang *et al.* [A9]), two papers on process mining (Kreye *et al.* [A4], Maruster and Alblas [A5]), one paper on design-business decision process integration, and one paper on supplier evaluation (Liu *et al.* [A6]). All the papers study the design processes that are aimed for *innovation*. All the design process innovations studied in the special issue explicitly address the *complexity* or *uncertainty* arising from the creativity, dynamism, and coupling of the diverse activities, evolving stages, internal and external stakeholders of the design processes.

For instance, crowdfunding campaigns address the *uncertainty* on the innovative designs against early adopters' preferences [A3] and the e-commerce data mining addresses the *uncertainty* on product specifications and customer needs [A9]. These approaches fulfil *design thinking* [A1], [A2] by mining online big data to better empathize with customers or early adopters for informing design decisions under uncertainty. By contrast, the other studies address the *complexity* and *uncertainty* associated with the events [A5], stages [A4], and internal [A10] and external [A6]–[A8] stakeholders in the design processes. Grounding those innovations is the *system thinking* on the complex design processes.

Among them, four papers proposed *data-driven* approaches to inform design processes, using data sources from online crowdfunding platforms [A3] and e-commerce web sites [A9], project-related work email data [A4], and event log data [A5]. These four papers address the Internet-based design process innovations to tag on *crowd intelligence*, including crowdsourcing [A7], [A8], crowdfounding [A3], and ecommerce site mining [A9]. Furthermore, the crowdfunding study [A3] relates to the innovative design processes in the context of *entrepreneurship* and startups, whereas six other studies are situated in complex engineering system design [A4]–[A8], [A10].

IV. Closing Remark

The processes of designing innovative products, services and systems are experiencing and demanding innovations and new paradigms in themselves, as represented by those covered in our special issue. Design thinking, system thinking, crowd intelligence, data science and artificial intelligence, entrepreneurship, and beyond, are converging in today's complex and uncertain design processes for innovation. Designing and managing the design processes toward the future requires a greater integration of theories, methods, and expertise from different disciplines, such as design, systems, computing, and management, and require common design frameworks and design languages to facilitate cross-field collaboration. It is our hope that this special issue will stimulate more research, education, and innovation initiatives that unite innovators from different fields to work together to push the boundaries of design processes for catalyzing human-centered innovation and solving the world's complex societal problems.

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Appendix: Related Articles

[A1] D. de Paula, K. Cormican, and F. Dobrigkeit, "From acquaintances to partners in innovation: An analysis of twenty years of design thinking's contribution to new product development," *IEEE Trans. Eng. Manage.*, to be published, doi: 10.1109/TEM.2021.3084884.

[A2] L. Przybilla, K. Klinker, M. Lang, M. Schreieck, M. Wiesche, and H. Krcmar, "Design thinking in digital innovation projects–exploring the effects of intangibility," *IEEE Trans. Eng. Manage.*, to be published, doi: 10.1109/TEM.2020.3036818.

[A3] C. Song, J. Luo, K. Hölttä-Otto, W. Seering, and K. Otto, "Crowdfunding for design innovation: Prediction model with critical factors," *IEEE Trans. Eng. Manage.*, to be published, doi: 10.1109/TEM.2020.3001764.

[A4] M. E. Kreye, P. J. Cash, P. Parraguez, and A. Maier, "Dynamism in complex engineering: Explaining uncertainty growth through uncertainty masking," *IEEE Trans. Eng. Manage.*, to be published, doi: 10.1109/TEM.2019.2937570.

[A5] L. Maruster and A. Alblas, "Tailoring the engineering design process through data and process mining," *IEEE Trans. Eng. Manage.*, to be published, doi: 10.1109/TEM.2020.3000861.

[A6] Y. Liu, C. M. Eckert, and C. Earl, "Assessing suppliers for complex products from the perspective of power," *IEEE Trans. Eng. Manage.*, to be published, doi: 10.1109/TEM.2020.2988056.

[A7] M. Shergadwala, H. Forbes, D. Schaefer, and J. H. Panchal, "Challenges and research directions in crowdsourcing for engineering design: An interview study with industry professionals," *IEEE Trans. Eng. Manage.*, to be published, doi: 10.1109/TEM.2020.2983551.

[A8] Z. Szajnfarber, L. Zhang, S. Mukherjee, J. Crusan, A. Hennig, and A. Vrolijk, "Who is in the crowd? Characterizing the capabilities of prize competition competitors," *I EEE Trans. Eng. Manage.*, to be published, doi: 10.1109/TEM.2020.2991370.

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[A10] M. Panarotto, O. Isaksson, I. Habbassi, and N. Cornu, "Value-based development connecting engineering and business: A case on electric space propulsion," *IEEE Trans. Eng. Manage.*," to be published, doi: 10.1109/TEM.2020.3029677.

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