Design Science
Why, What and How – Revisited

Papalambros, Panos; Gero, John; Maier, Anja; Cagan, Jonathan; Ahmed-Kristensen, Saeema; Albers, Albert; April, Kurt; Blessing, Lucienne; Kleinsmann, Maaike; More Authors

DOI
10.1017/dsj.2025.10026

Publication date
2025

Document Version
Final published version

Published in
Design Science

Design Science

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Received 19 July 2025
Revised 19 July 2025
Accepted 19 July 2025

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Des. Sci., vol. 11, e48
journals.cambridge.org/dsj
DOI: 10.1017/dsj.2025.10026

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Abstract

Design Science is the discipline that studies the creation of artifacts – products, services, and systems and their embedding in our physical, virtual, psychological, economic, and social environments. This editorial is a collective effort of the Design Science Journal's editorial board members, past and present. The journal's inaugural 2015 editorial, "Design Science: Why, What and How," reflected the thoughts and vision of that first editorial board for the new journal and the discipline it represented. The present contribution offers the reflections of editors who served the journal in the past 10 years. The individual contributions were not primed and are presented here unedited for conformity or consistency. Differently from the 2015 editorial, there is no effort to synthesize the individual contributions, leaving the task to our readers, who can draw their own conclusions about the Design Science Journal and community accomplishments to date, and the challenges ahead.

Keywords: Design, Designing, Design Science, Engineering Design, Product Development

Introduction

The Design Science Journal celebrates its 10th anniversary since it was launched in 2015. From its inception, the journal has had at least two editors-in-chief (EICs) with diverse expertise to signal its desire to welcome contributions from the wider design community. Panos Papalambros has served the journal as EIC and John

Gero as co-EIC since its launch. Anja Maier and Jonathan Cagan joined in 2025 as co-EICs to allow for an orderly, gradual transition of journal leadership. The original editorial board is also gradually transitioning to new members.

The journal is a collaboration of the Design Society and Cambridge University Press. The journal owes its launch and continuing presence to the support of the Design Society leadership and members. The Cambridge University Press publishers and administrators have been hugely supportive of the journal over the past 10 years, and the journal community is most grateful for that.

This editorial is a collective effort of the Design Science Journal's editorial board members, past and present. The journal's inaugural 2015 editorial, "Design Science: Why, What and How," reflected the thoughts and vision of that first editorial board for the new journal and the discipline it represented. The EIC team reached out to current and past members of the editorial board, asking them to share their thoughts at this 10-year mark. The present contribution offers the reflections of editors who served the journal in this period. The individual contributions were not primed and are presented here unedited for conformity or consistency. We stipulated limitations only on length and referencing. Differently from the 2015 editorial, there is no effort to synthesize the individual contributions, leaving the task to our readers, who can draw their own conclusions about the design science journal and community accomplishments to date, and the challenges ahead.

The editorial starts with comments from the original EICs, followed by the newly joined EICs. The contributions of the editorial board members are then presented in alphabetical order.

Editors-in-Chief

Panos Papalambros and John Gero

Design is how we humans change the world. We do this by creating artifacts – products, services and systems. Design Science is the discipline that studies the creation of artifacts – products, services and systems and their embedding in our physical, virtual, psychological, economic and social environments. Ten years ago, in 2015, we started the Design Science Journal to support this discipline and the researchers engaged in it. Now in 2025, we are pleased to be with you all – readers, authors, reviewers and administrators – and to report that your journal is here in good health to serve the design community and to share your contributions to design knowledge and its propagation.

Our masthead then and now states that "*Design Science* aims to serve as the archival venue of science-based design knowledge across multiple disciplines. The journal facilitates communication across diverse fields and serves as a bridge across several communities, publishing original research with a strong emphasis on accessibility by scholars from a diversity of disciplines." We actually changed the tense above from future to present, because what was largely a wish in 2015 is largely a fact in 2025. *Design Science*, as a journal and a community, celebrates all design activities, including all design journals, and remains committed to serving as a meeting point of those who care about how we change the world around us and how we can be wiser in seeking positive changes for everyone affected directly or indirectly.

We invited our editorial board to share their thoughts on this 10th anniversary of the journal, reflecting on the 2015 inaugural editorial "Design Science: Why,

https://doi.org/10.1017/dsj.2025.10026 Published online by Cambridge University Press

What and How." We provided no further guidance, and we offer the readers no summary synthesis of their thoughts. This is intentional, as we would like to challenge our readers to draw their own conclusions, particularly on design science as a discipline.

When we started the journal, we were often asked the question of what kind of papers we want in the journal or what *exactly* design science is. We probably gave some rather evasive answers, but insisted on scholarship. We also insisted that the papers should be sufficiently accessible to the non-expert potential reader to convince them to learn more about whatever the article dealt with. Such accessibility could be accomplished through longer introductory sections or the avoidance of excessive jargon with no definitions of terminology. The questions above are answered directly by what we published, and we need not be evasive any longer. The journal espouses the notion that design is carried out not only in the traditionally nominated design disciplines but also in disciplines where the creation of services and systems is less apparent. Expectations on scholarship, rigor and accessibility remain strong, emphasizing continuing effort and improvement. The journal serves both authors and readers by helping present the research work in the best manner possible. This can be accomplished only through the selfless dedication of the reviewers, to whom our entire board is fully indebted.

The journal has also been blessed to have a wise and hard-working editorial board whose thoughts we now share.

This year, 2025, our editorial team welcomed two new Editors-in-Chief, Anja Maier and Jonathan Cagan, to whom we extend our warmest welcome.

Anja Maier

As we celebrate the Design Science journal's 10th anniversary (Papalambros 2015) and as the new Co-Editor in Chief, my vision is for the journal to serve as the premier global space for multifold human designer voices to meet, grow and thrive. Creating design science futures, I offer a threefold call to action, individually and collectively: Asking, Connecting and Impacting.

One: Asking – how might we prompt ourselves to think as humans

Creating design science futures, I call for us to be deliberate about asking and crafting (research) questions. Questions create futures. Imagining possibilities through questions generates, re-generates, dares to care. In a time of natural urgencies, technological pace and social transformation, design science futures are not about perfecting answers, but about the courage and clarity of the questions we ask. The question, the process of inquiry, is not merely a precursor to discovery; it is the design itself (Price & Lloyd 2022). As human design researchers and human designers (Maier & Cash 2022), we need to (re-)learn the skill of asking questions.

The discipline's future lies in embracing a more deliberate culture of imagining and crafting questions, beyond questioning. Too often, we chase questions that are measurable but not meaningful. The future demands more of us: to frame problems that challenge the status quo, disrupt technocentric perspectives and reflect social, environmental and ethical contexts. The next evolution of design science must prioritize the quality and framing of the questions we ask. In that way, design science will (re)evolve into a discipline that remains human.

https://doi.org/10.1017/dsj.2025.10026 Published online by Cambridge University Press

Tomorrow's most impactful innovations will not emerge from answers optimized in isolation, but from questions grounded in lived experience, systems thinking and moral imagination. We must cultivate a design research culture that values the crafting of meaningful, generative and disruptive questions. This means interrogating the assumptions behind our definitions of value, innovation and success. It means reflecting on the voice we take and the future we are implicitly or explicitly designing into our systems. The future of design science is shaped by researchers trained not only to build artefacts, but to build theory- and practice-based rigor, imagine multiple futures, solve problems worth solving and ask questions worth asking.

Two: Connecting – how might we embrace researching at intersections as generative spaces

I see the journal actively continuing to embrace and promote interdisciplinarity – across the variety of design research and across the arts and humanities, the social-, the engineering- and the natural sciences. Designing happens in and through a web of connections, and design science thrives where disciplines converge, intersect, collide and reconfigure. Writing for multiple audiences (possibly in a fusion of research cultures) is not easy. It demands humility, curiosity and an acceptance of methodological plurality (possibly seen as messiness) and rigor in that plurality. This is hard. But it is possibly precisely this messiness and rigor in plurality that allows for the most creative and robust solutions to challenges ranging from local to global. In a world increasingly shaped by complex situations from pandemics to planetary sustainability, no single discipline holds all the answers. Design science can serve as the connective tissue that makes interdisciplinary work actionable.

Design science has always lived at the boundaries of disciplines, but its future depends on embracing those boundaries as generative spaces (McMahon & Maier 2024). Whether it is sustainable energy systems, ethical AI, healthcare innovation, or urban resilience, today's socio-technical engineering systems are inherently interconnected (Maier, Oehmen, & Vermaas 2022a). They require insights from multiple disciplines, including form anthropology, design engineering, economics, ecology, medicine, physics, psychology and political science, to name a few. The most powerful design interventions are born from interdisciplinary – and methodological cross-pollination. Going forward, design science must therefore remember to be(come) fluent in many "languages": including the precision of computational modeling, the nuance of qualitative inquiry, the urgency of policy debate, and the creativity of the arts. It must also cultivate the humility to listen, to connect and to nurture the courage that allows it to continue doing what it is well known for: synthesis.

Three: Impacting – how might we recognize and report on design impact beyond academia

Theoretical rigor must go hand in hand with practical relevance and impact beyond academia. Designing is generating societal change. Impact cannot be an afterthought. It is a responsibility. It must be designed into research from day one, a design constraint from the outset. Design science research must be embedded in communities, organizations and policy frameworks, not simply to test ideas but, most importantly, jointly to create ideas. The discipline's legitimacy will

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increasingly be judged not by citations but by consequences. The field must report on how it engages more directly with the messy, real-world systems it seeks to influence. I would like to create a paper category in the journal called Design Impact. Offering a model to report on embedding design research in industry and policy contexts, keeping societal value in view. As design scientists, we have already reported and will continue to do so on methods, demonstrators and tools used beyond academia, but we also need to move to reporting on governance models, on behavioral nudges and on perspectives. In this design, science must adopt a broader metric of success than citations: it must acknowledge effects on sustainability, equity, adaptability and inclusion. It must also evolve to report on the variety of its outputs beyond peer-reviewed journal manuscripts, for example, including white papers, digital platforms, living laboratories and open-source toolkits that reach people where they are.

Concluding, I see the future of design science as designing pathways and directions, designing connections and whole systems, calling us to (re)-think how we will measure our success with the purpose of designing better futures. It means training scholars who are not only skilled research methodologists, but also system thinkers, translators and ethical actors. It needs bold, thoughtful design scientists who can ask: What should and what ought to be? And then build toward those answers, not alone, but with others. This is coming back to the future of Simon (1969), compellingly drafting that design is about imagining and creating what ought to be, positioning design as a science of transformation. To keep strengthening the realization of this powerful foresight in researching and designing responsible, sustainable and natural futures, design science futures must grow in three crucial dimensions: by re-centering the human design researcher and human designer on the importance of asking questions, researching at intersections and ensuring impact beyond academia.

Jonathan Cagan

Design science as a field is more important today than ever before. Humanity is at a time with unprecedented challenges, from water shortages to weather-based disasters to clean energy scarcity, to cyber threats to health crises and more. And humanity must design its future. So we must understand how to design and how to create new ways to design, within the context of this change. To do this, we need to understand designing through the lens of fields such as social science, cognitive science, physics, biology, engineering and industrial and communications design, and how they influence how people design and what they can design.

A purpose of *Design Science* is to facilitate communication across diverse fields and serve as a bridge across communities, and to motivate scholars from diverse fields to pursue work with direct applicability to design. Such collaborations and connections are critical to addressing these challenges.

But the approach must be rooted in the rigor of science. Scientific discovery and design creation have many fundamentally equivalent methods and goals – the creation of something new in a methodological and analytical way that is repeatable, formal and codifiable either through algorithms or heuristics (Cagan, Kotovsky, & Simon 2001). Human experts solve difficult problems, such as design, via selective searches through problem spaces that are sometimes very large, but their searches are efficient by recognizing familiar patterns and even flashes of

https://doi.org/10.1017/dsj.2025.10026 Published online by Cambridge University Press

insight, associated in memory at times through incubation, leading to understanding of how to proceed when a particular pattern is present. There is, then, a scientific basis for design (rooted in problem solving).

Herb Simon's *The Sciences of the Artificial*, published in 1969, argued for a scientific approach to the design or creation of new solutions to problems (Simon 1969). Simon stated that design is "devis[ing] courses of action aimed at changing existing situations into preferred ones" and that "design…is the principal mark that distinguishes the professions from the [natural] sciences." Arguably, design as the field we know today was directed or at least inspired by *The Sciences of the Artificial*. *Design Science*, as a journal, is rooted in this argument. As Simon also stated: "The proper study of [human]kind is the science of design."

The physical, digital and biological disciplines are converging through explosive (and exponential) growth in resulting technology and are poised to transform and integrate with humankind. To understand how to design in this technological and human ecosystem is one area where *Design Science* can play an impactful role. Understanding how people from across disciplines think when solving wicked problems, how they discover innovative solutions or paths to such solutions and how to better enable people (alone, through teams, or with artificial agents) to reach those solutions is very much the point of this journal.

As a community, we are in a position to study this process, and *Design Science* is a focal point for communicating these studies and their findings and translation to use. I look forward to seeing the many exciting papers in this area in *Design Science* and their impact over the next 10 years.

Editorial Board Members

Saeema Ahmed-Kristensen

Ten years ago, for the *why, what and how* of Design Science (Papalambros 2015), I wrote of the complexity of products and their changing nature, the need to understand people, process and organization, describing the *what*. The *why* described some of the drivers informing future research agendas, for example, emerging digital technology and its adoption, and the *how* discussed the methods and directions. As Design Science hits double digits. I revisit where we are today by starting with the *why*. These reflections are personal and shaped by my research, context and perspectives.

The broad driver of digital technology remains relevant to current design research questions. In 2015, the focus was largely upon the adoption of emerging digital technology such as additive manufacturing, generative design, AI and the large availability of data from IOT into products and manufacturing processes, and the impact on the types of products and product development processes needed. The impact of digital technologies on the changing nature of a physical product led to research considering the modeling of both digital and physical elements, and to better understand the subsequent impact on the engineering and product development process required for this transition. Since then, the adoption of agile processes into planned product development processes has become widely accepted. The impact on products has extended to also consider the design of interfaces and has evolved to consider the product as part of a wider system. This is due to both the digital economy and a greater sense of responsibility of design to

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include sustainability and the wider impact of the research on individuals, society and the planet. This is a second driver, and although in 2015 there was also research in Product Service Systems and Design for x, Life-cycle Analysis, the nature and scope of what is researched has involved.

Digital technologies, and in particular with the availability of big data, or real-time data from sensors, we have seen that data-driven/ data-informed or data-enabled design has become an increasingly popular research field. The transition and impact of, for example, adopting big data into a product is described by Porter in steps from a smart product through to a connected system, and systems of systems (Porter & Heppelmann 2014). The review of Lee & Ahmed-Kristensen (2025) has brought disparate research together in a framework identifying the seven key activities where data can be used to drive the design of products, services and product service systems. Thus, the relevant nascent field has begun to mature, many of the seven activities where we can see the use of large data sets, such as customization of products, predictive maintenance or discovering user behavior are established as long standing research areas of design science, but the exact questions and the *how*, which involves the drawing together of quantitative and qualitative research methodology has evolved in particular where humans are involved.

In terms of *what*, Generative design and working with AI tools (fuzzy logic, neural networks, etc.) together with understanding creativity or design cognition has been a design science research question for a while, often researched by different communities of researchers. Human behavior, both the understanding of users and designers and design cognition, was and remains central to Design Science research. With the increased availability in the last few years and accessibility of general artificial intelligence, in particular Large Language models, however, the focus has shifted to how we can design with digital technologies, AI (more specifically with LLM or image generation tools) thus requiring understand both human and algorithmic reasoning (e.g., Zhang, Han, & Ahmed-Kristensen Zhang, Han, & Ahmed-Kristensen 2025), behavior and limitations and has brought together the two communities. The *what* is now Human and AI behavior.

Overall, the long-term questions of design science remain; the why is shaped by the world around us, and thus our focus (the what) and how the research is tackled are constantly evolving. With Design Science, we hoped to shape more than the community of design society research, and that remains an ongoing ambition, which is even more timely now.

Albert Albers

To understand design science, we need to understand design first. Design in engineering is the creation and validation of a product or a system that is successful in the market – a real Innovation. Due to the increasingly complex products and technical systems of the 21st century, we need to be more specific:

Design in engineering is the creation and validation of complex cyber-physical systems that are successful in the market and for society.

Now that we have our understanding of design in our context, we can introduce design science. The relevance of science in engineering goes back as early as 1856, when Ferdinand Redtenbacher defined the necessity of science for engineering (Redtenbacher 1991). He was convinced that mechanical engineering was more than experience and craftsmanship; he understood it as a science based on

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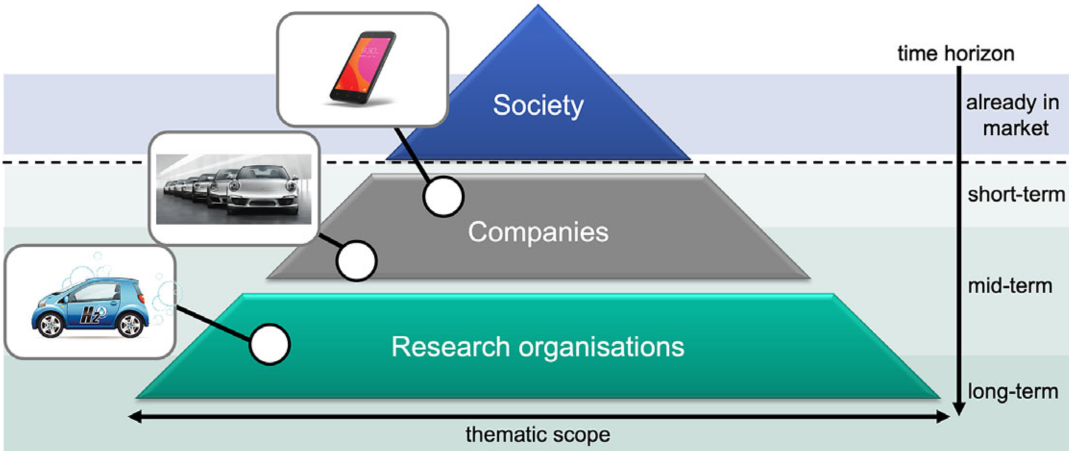

Figure 1. Time horizons and thematic scope with examples (Albers 2018).

mathematical and physical principles. In a time when a mechanical engineer was considered a better mechanic, Redtenbacher focused on the scientification and mathematization of engineering to systematically understand and design machines and to use and support the individual creativity of the involved "Konstrukteure," the Designers (Redtenbacher 1991).

As detailed in a Keynote at the DESIGN conference (Albers 2018), design science needs to be understood with three different time horizons (Figure 1): The scientific fundamentals forming the long-term horizon, the scientific cooperation with industry supported by cooperative research funding of the states forming the mid-term horizon, and the direct application from companies for society as the short-term horizon. Implicitly, society demands technical solutions to solve problems like energy supply, mobility, nutrition, health care, or housing needs. Therefore, the demand for technical solutions by society creates a pull effect from the companies to supply the technical solutions to the problems. To be able to supply these solutions, skilled personnel are needed within the companies, though in design to create the solutions. The demand for skilled personnel by the companies creates again a pull effect, this time from the research organizations. The skilled personnel are educated by research organizations and enabled to design the technical solutions. In engineering design, examples at the product level can be made for the three different time horizons. In the short-term horizon, 0–3 years is the duration until the predicted market launch. This is the time it takes for the knowledge generated in science to turn into innovations, successfully sold by companies. Research in this time horizon is mostly carried out by companies. An example here is the next generation of smartphones. In the mid-term horizon, which is in the focus of industry-academia collaborations, it takes 3–6 years for this process to be completed, for example, for the next generation of a car to turn from knowledge into an innovation. An example of the long-term horizon of more than 6 years is a future generation of drive concepts or completely new concepts for the circular economy, where the research is usually entirely performed by research organizations, for example, in Germany, funded by the DFG or the EU. (Albers 2018).

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Research is needed to generate knowledge that can then be useful to companies, and ultimately the society can benefit from it. Design research is, therefore, the central source of knowledge based on which methods, tools, processes and new technical concepts can be designed to support the development of technical solutions (Albers 2018). Therefore, we can see design science as:

Design science is researching the understanding of the processes of creation and validation of socio-technical systems and products in practice and the knowledge-based development of methods, tools, processes and technical solutions to support and improve the problem-solving and, therefore, solution-generating processes in companies for society.

This, for me, is our Mission and Challenge as Researchers in Design Science!

Kurt April

The imperative of design science for Africa's future

Despite considerable academic output, management research in Africa remains predominantly retrospective, focused on explaining what has occurred rather than on shaping what might be. This explanatory orientation has contributed to an increasing disconnect between scholarly inquiry and the lived challenges of communities, organizations and policymakers across the continent (van Aken & Romme 2009). The time has come to adopt a more actionable paradigm – design science – that enables scholars to actively create and test innovative solutions to Africa's most pressing societal challenges. Nowhere is this need more urgent than in under-resourced African contexts, where systemic challenges in governance, infrastructure, entrepreneurship and service delivery persist. These environments are not merely sites of scarcity; they are crucibles of innovation. Yet, the prevailing research culture tends to overlook these conditions, treating them as anomalies rather than opportunities for design-led problem solving. Praxistical design science, by contrast, embraces the complex realities of such settings and mobilizes iterative cycles of building, evaluating and refining solutions in collaboration with stakeholders (Gregor & Hevner 2013).

Design science, as articulated by Simon (2019), seeks not merely to understand the world but to change it. It draws on the best available knowledge, be it theoretical, empirical, or experiential, to construct "how-to" artefacts: models, processes, systems, or tools that solve real problems. These artefacts are not static; they evolve through rigorous evaluation by designers who promote indigenous African knowledge and co-develop culturally responsive design practices and processes in specific contexts (Eriksson, Motlhanka, & Mosepedi 2023). For African scholars, this is an invitation to move beyond theorizing about change and toward actively engineering it.

The opportunities are vast. In the realm of responsive supply chains, design science can help overcome the unpredictability and fragmentation that characterize many African logistics systems. Iterative design approaches can generate adaptive coordination models that reflect regional constraints and capabilities. Likewise, in collective governance arrangements, among cooperatives, civil society networks, or informal economic clusters, design science can uncover scalable mechanisms for participatory decision-making, trust-building and conflict resolution (Lukka 2003).

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Entrepreneurial ecosystems, particularly in underserved urban and rural areas, also benefit from design interventions. Traditional models of incubation and support often falter when transposed into African contexts without adaptation. Through design science, scholars can co-develop entrepreneurial platforms that are grounded in local realities and responsive to evolving needs (Baskerville *et al.* 2018).

Importantly, design science is not a call to abandon rigor; it is a call to redefine it. When relevance and rigor are brought into productive tension, research can produce cumulative design knowledge that improves both theory and practice. For African scholars, in particular, this shift holds transformative potential. It allows us not only to explain the past but to design the future – responsively, collaboratively and contextually.

Lucienne Blessing

Design science: quo vadis

We are surrounded and affected by designs intended to address an identified or perceived desire, need, or problem: these include physical and virtual artifacts, intangibles such as actions and procedures, and systems such as transportation or education. Designs are meant to effect change: changing the way people think, act, or experience, or changing context, course, or boundaries. Deep understanding of current and future desires, needs and problems of the target users, stakeholders, society and the environment, as well as intended use and context, increases the chance of a successful change, but only if the knowledge required to create a feasible design is available, and the possible impact – intended and unintended, positive and negative, short-term and long-term – on users, stakeholders, society and environment are taken into account. Design causes Change; Change causes Impact.

Designing requires a wide range of knowledge (factual, conceptual, procedural, or strategic) ideally obtained through scientific inquiry, that is, a systematic search for knowledge based on the best available evidence and brought together in a structured body of knowledge to "support proper actions, judgments, and evaluations" (Eekels & Roozenburg 1991).

For a long time, design science was considered unnecessary or impossible: design could fully rely on knowledge created by other sciences. Design, however, also has its own substance, which requires scientific inquiry in order to build the foundation necessary for design to make a positive and lasting impact on individuals, society and the environment.

Design science aims not only at systematically developing and validating knowledge about the phenomenon of design (in the sense of process and object) but also aims at the development and validation of design support founded on this knowledge (Blessing & Chakrabarti 2009).

Design science is a relatively young field, dealing with a very complex phenomenon that combines natural law, human purpose and continuous change. The scientific efforts in the last decades – empirical, theoretical and methodological – have substantially improved our understanding of design, the quality of our research and our position as a scientific discipline, but further effort is required. Our knowledge production is messy, affecting the visibility, strength and coherence of our outcomes and, hence, their impact: agreed upon definitions of basic concepts

https://doi.org/10.1017/dsj.2025.10026 Published online by Cambridge University Press

are lacking; research results are sprinkled throughout literature rather than integrated in a shared body of knowledge; theories and models are not widely used; validation is weak; young researchers often are confused; methodologies and methods from other disciplines are used without proper assessment of the underlying principles and theories and the impact on practice remains sporadic. We still do not "share a common view of what are appropriate research methodologies, what are the difficult unanswered questions and what constitutes high quality research" typical of a mature field (Finger & Dixon 1989).

Concerted efforts are needed to establish a common paradigm (or paradigms), to develop a structured body of knowledge and to create a sound methodological foundation, not only to distinguish ourselves from other scientific communities but, more importantly, to guide the research activity and ensure high-quality, impactful research.

Jean-Francois Boujut

Design science for a sustainable future …

Over the past 30 years, we have witnessed a profound transformation in engineering practices and organizational models. Post-World War II paradigms – characterized by top-down, hierarchical, company-centric approaches – have gradually given way to more fluid, user-centered and adaptive frameworks. Tackling complexity seems to be one of the major challenges modern societies must face today, and, as part of society, companies, organizations of any kind. In this context, organizations, institutions and companies can no longer afford to operate under traditional assumptions. But what methods should help? What theoretical foundations and philosophical principles should guide them?

Design as a discipline is rooted in some invariant principles. Frameworks such as C-K theory, the Double Diamond model and various cognitive approaches have captured some of these constants. Over the last 50 years, the design research community has accumulated a vast and valuable body of knowledge. This is an incommensurable asset, but only known by a few academics or educated engineers, or designers…. One of our critical challenges is to democratize this knowledge. Revealing the designer within each individual could empower broader societal participation in shaping a better future.

Today's rapidly evolving world is testing the limits of our current models. Social transformations have altered the ways people interact with technology. Smartphones, IoT devices and a web of interconnected technologies now permeate our everyday lives. The design of these artifacts cannot be separated from their social context. No longer is it possible to disconnect the creation process from societal changes and people. Increasingly, people are no longer limited to the position of users; they are considered as co-creators and active participants. Design has moved beyond the realm of experts to reach a wider audience while at the same time remaining a very technical activity that requires specific and complex skills.

Facing climate change is also a deep and urgent concern that design science should address. Under the pressure of younger generations, academic programs are progressively integrating sustainability, frugality and even degrowth into engineering and design curricula. Concepts such as planetary boundaries, low-tech innovation and strong sustainability are no longer fringe ideas – they are at the heart of emerging research agendas (Bihouix 2020; Gaultier, Masclet, & Boujut

https://doi.org/10.1017/dsj.2025.10026 Published online by Cambridge University Press

2024). These shifts compel us to revisit and challenge our theoretical foundations, including the mental models that underpin them.

Moreover, our field must expand beyond its traditional focus on capitalist enterprises. Nonprofit organizations, grassroots initiatives (local production), territorial projects (urban factories) and open-source collectives are also important spaces for design. Movements like Open-Source Ecology or France's L'Atelier Paysan offer alternative visions of production – centered on autonomy, collaboration and environmental stewardship (Bonvoisin, Mies, & Boujut 2021). These groups are pioneering new modes of design and manufacturing that reflect deeply held societal values.

Why should researchers in design science pay attention to these developments? Because they signal a transformation in how design is practiced, understood and valued. Classical models – whether for decision-making, product development or business – are being questioned and reshaped. This presents an exciting opportunity for our community.

As scholars and practitioners, we must actively contribute to this shift. Design is central to navigating today's challenges. Our role is to generate knowledge, develop tools and create frameworks that support inclusive, democratic and collaborative design practices – helping to shape a more sustainable and equitable future.

Marco Cantamessa

Design Science: moving from impact to Impact

When Design Science was launched 10 years ago, one of the ideas was to develop a platform for multidisciplinary advances in the academic and industrial understanding of design, such as to support a scientifically grounded approach to the practice of design. By analogy, the idea was to bring to design what the concept of "Management Science" had done to the profession of management. Have we reached this objective and what is still missing?

If one browses the papers published in the journal, I would answer "quite so!." It's hard to find another journal in which the topic of design is covered with a similar shared philosophy. Most papers are multidisciplinary, but without being superficially generalist. The authors focus on the root phenomenon of *design per se*, also breaking loose of their own backgrounds within the many branches of design (i.e., "engineering," "industrial," etc.). They take a broad view of design, but without indulging in pure conceptual speculation. The attention paid to the scientific method is strong, but without losing a view on industrial implications.

So, what is still missing?

One obvious answer is popularity, readership and impact, which I think is significantly less than the journal deserves. This is probably due to the ongoing inflationary phenomena in academic publishing, where quantity and bibliometric indicators tend to overwhelm substantial quality and insight. A stronger effort by the community to nurture the popularity of the journal is not only due but also likely to be advantageous.

Secondly, I think that the relevance of Design Science to the world of 2025 is even higher than in 2015. The world today is ever more turbulent, and a significant part of this is associated with the dynamics of technological innovation and its connections and ramifications with broader dimensions, such as economic, geopolitical and social. Now, at the heart of technological innovation is the design

https://doi.org/10.1017/dsj.2025.10026 Published online by Cambridge University Press

process (Isaksson *et al.* 2019; Montagna & Cantamessa 2019), that is, the cognitive phenomenon by which individuals, groups and organizations bring together diverse forms of knowledge and create new systems and artifacts. This link is crucial and should probably become a stronger issue both within the community and when disseminating the results of research to broader audiences. In fact, many scholars and practitioners who deal with innovation from a managerial and economic standpoint, but without understanding the "inner circuitry" of design, risk ending up with superficial studies and decisions. At the same time, focusing on design without understanding the bigger picture within which it occurs leads to the risk of limiting the relevance of the work being done.

In sum, this is a journal that still has limited impact (bibliometric, with a small "i") but with the potential of delivering a significant Impact (to the world, with a big "I").

However, this transition will not occur without some further commitment by all.

Gateano Cascini

For several years now, we have been repeating the mantra that we are living through a time of transition – a moment shaped by profound transformations, some already underway, others just on the horizon. These changes are driven by the consequences of climate change, by the growing social pressures due to the expanding differences between the rich and the poor ones, between the Global North and the Global South, and by the rapid evolution of digital technologies, particularly the radical shifts enabled by Artificial Intelligence.

We have realized that the complex challenges posed by sustainable development, encompassing environmental, social and economic dimensions, necessitate a systemic approach. This, in turn, requires a shift in focus toward the (re) definition of policies, with the assumption that they will be implemented and respected. However, achieving this requires building mutual trust within the global society, a stark contrast to the geopolitical trends of the past decade, which have been dominated by individualism, fear and too often hatred, along with the resurgence of nationalism and sovereignty, which are manifestations of social fragmentation, not cohesion. These are not just political phenomena; they are emotional and cultural currents that influence how people perceive change and their place within it.

In this context, design – understood as the conscious and cognitive effort to change an existing situation into a preferred one – claims a central and urgent role. Design is not simply about creating artifacts or services; it is a critical means of navigating complexity and catalyzing transformation.

So, in light of all this, what are the directions that design research should take in the years ahead? I'm sure the DSJ editors and the colleagues who contributed to this anniversary issue will offer thoughtful and inspiring research agendas. Personally, I'd like to highlight one aspect that I feel our community too often overlooks: the importance of designing visions for the future.

It's a bit of a chicken-and-egg question I often pose to my students: what comes first in the innovation process – research (as a formal, systematic effort to expand knowledge) or design (as the creation of something new)? As engineers, we usually build innovative solutions by applying ingenuity to state-of-the-art scientific

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knowledge. But the incremental nature of this process is starting to show its limits. It's clear that in today's context, something more is needed.

Sometimes, it's the visionary idea that comes first – an idea that might seem impossible, but that ends up pushing scientific research to explore new paths. In this sense, design creativity – the ability to propose novel and effective solutions – is only half of the coin. The other half is the ability to interpret what's happening now, look ahead and imagine scenarios where today's conflicts are overcome and collective action can actually take place. What we need is not blind optimism or utopian dreaming, but a society that's able to envision meaningful futures – futures that acknowledge the trade-offs and failures that come with any transformation, but that are rooted in the one thing all living organisms share: the capacity to evolve in ways conducive to life.

This is the most critical missing element in too many research endeavors.

Therefore, I hope to see articles in this journal, as well as in sister journals within our community, addressing research questions such as: How can we nurture envisioning skills? What engineering methods and techniques can enhance the individual and collective ability to understand where current decisions are taking us? How can we integrate vision-building competencies into engineering curricula? What massive participatory processes can enable envisioning future priorities without a clear trend toward them? And many others…

Happy Anniversary, DSJ! Here's to another decade of rigorous, creative and forward-thinking scholarship – and to the visions we have yet to design.

Amaresh Chakrabarti

What

Science refers to systematic studies for developing knowledge about some system of interest and/or its behavior; the knowledge so developed is:

- "purposeful": it serves a purpose that is either "descriptive," that is knowledge about the system or its behavior "as is," or "prescriptive," that is knowledge about the system or its behavior "as should be" (Blessing & Chakrabarti 2009).
- "generic": the knowledge produced has some degree of generality, that is, it applies to a variety of specific systems and behaviors; the more generic the knowledge is, the better it is considered to be, for its greater reuse value
- "valid": the knowledge produced is "true" or "correct," something that is possible to be demonstrated and
- at the time of its development, "new" that is, it has at least some elements that distinguish it from all existing pieces of knowledge or context in which it is applied.

We take design science (Chakrabarti 2015) as having two broad foci: understanding and supporting (a) design and/or designing and (b) its relationships with its "facets," where "facets" are the baskets of factors, such as people, product, process, etc., that influence and/or get influenced by designs and designing.

Why

According to Chakrabarti (2015), Simon (1969), "a design is a plan for intervention which, when implemented, is intended to change an undesirable situation into a (less un-) desirable one. Designing (that is to design) is the process of identifying

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these situations as well as developing designs to support the transition." However, designing does not automatically guarantee that the designs, when implemented, will work or work well. Hence, the need for understanding designs and designing, and their relationships with the facets, and based on these, develop prescriptive knowledge for improving the act of designing, better addressing or taking into account the facets in play, or developing improved designs.

How

For the sciences is general, philosophy of science is the area that addresses this question; the outcome is called a *research methodology*: the accepted framework and associated methods for carrying out science in an area, and the kinds of outcomes considered to be scientifically valid. In design science, these are termed *design research methodology*. Various such methodologies have been proposed, including DRM (Blessing & Chakrabarti 2009). According to DRM, each piece of design research should undergo one or more of the following four stages: (a) Research Clarification: identification of research goals called "success criteria"; (b) Descriptive Study I: development of descriptive knowledge of what (currently) "influences" success criteria, how well and where the gaps are; (c) development of prescriptive knowledge, termed "support," for improving the influences on success criteria and (d) evaluation of how well the support is likely to influence success. The overall process is iterative across these stages.

Lin Lin Chen

One of the obstacles to the growth of design as a discipline is the lack of high-quality journals. As the discipline grows, so does the need for channels to share knowledge and build a common foundation. In 2015, "Design Science" was founded in response to this need for high-quality journals by the collaboration between the Design Society and the Cambridge University Press. The journal also aims to bring together design researchers – who are all working on Design, but from the confines of different disciplines – and thus provide a bridge to explore possible commonalities.

Ten years later, in 2025, it is great to see that Design Science fulfills its vision and has established itself as one of the best-recognized journals in design. The wide acceptance is evidenced by the fact that the 254 articles published between 2015 and May 2025 were contributed by many authors from different countries and continents. In addition, a significant percentage (94/254) of the articles are the results of grants from national or regional science agencies. The published topics spread across several design research areas, including design cognition, design process, design education, design teams, participatory design, AI, design methods, psychology, social networks, systems engineering, consumer experience and many more. Thus, "Design Science" has very successfully achieved the goals that it set out to achieve.

Looking forward, I see AI making a great impact on all aspects of design, design education and design research. Designers are already incorporating today's AI tools in their design processes to speed up the exploration of different design concepts, but also in prototyping and validating. How will the design process evolve with AI tools and, in the future, AI agents? What shall be the competencies of a designer in a future with such powerful thinking tools? What can design as a

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discipline contribute to humans in such a future? Beneath all these questions is my firm belief that the essence of design – creativity, technology literacy and a deep understanding of people – will become even more important in the future.

AI is also changing the journal publication landscape. At the International Journal of Design (IJDesign), I have seen several folds of increase in submissions since the popularity of AI tools. The language barriers have been lowered, but the contents and depth of research largely remain the same. On the one hand, I am happy that AI tools enable many more design researchers to present their ideas in a foreign language that would require many years to master, if ever; and I know of excellent design researchers who were able to present their results much better with AI tools at their hands. On the other hand, these AI translation tools, of course, do not change the originality, significance and impact of their research. How shall a journal that wants to maintain high quality operate when facing a huge influx of AI-assisted content?

What shall be the next phase for "Design Science," or design research in general?

John Clarkson

Design processes produce designs. There is ample evidence to support this simple statement in the world around us. What is less certain is how to characterize the design processes that produce "good" designs, where "good" might convey the sense of being of a high (or at least satisfactory) quality, useful for some purpose (specified, implied, or generally understood), worthy of approval and viable (within a given commercial or social context).

This opening paragraph, copied from my previous contribution to the Design Science editorial, remains valid 10 years on – the quest for the optimum process to deliver a "good" product, and more importantly, the evidence-based guidance to define such a process, remains. The presence of multiple models of design[ing] helps provide perspectives that both resonate with practice and challenge practice. However, the more complex the product or service, the more challenging it is to design and deliver an optimal, or even effective, design process – particularly one that delivers a "good" solution to the "right" problem.

As my own research and practice have shifted from engineering toward health and care, inclusive design and policy development, it has become increasingly apparent that adopting a systems approach to problem solving and, more importantly, problem seeking is an imperative. Such an approach could focus on a range of perspectives, for example, people, systems, design, risk and management (Clarkson 2018), a structural, practice-based model of the process (Design Council 2005; INCOSE UK 2024), or a theory of change (Weiss 1997). In all cases, emphasis is given to the role of problem seeking as a necessary prior to effective problem solving.

This view has been reinforced over the past few years in conversations with nearly 100 Policy Fellows recruited to the Royal Academy of Engineering (Royal Academy of Engineering, Accessed: July 2025). As Fellows, each with a unique policy challenge, they are introduced to the concept of a systems approach (Royal Academy of Engineering, Accessed: July 2025) via a half-day interactive workshop and invited to conversations with a number of experts in their field and myself to follow up on the systems workshop. My observations of these conversations is that

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they often follow a familiar pattern: the Fellow will introduce their challenge, chosen with reference to a specific strategic issue and reflect on its overwhelming complexity; I will suggest that their idea of the challenge (or problem) is really just context to the real problem(s) that they are trying to solve and we will then discuss this dilemma and alight on a number of avenues that might reveal the problems that can (or should) be solved as part of a wider challenge. This may be accompanied by reference to design-led methods, such as systems mapping (rich pictures, DSMs and causal loop diagrams), risk assessment (bowtie method), stakeholder analysis (real needs and personas), boundary setting (influence and interest) and theory of change.

An hour later, we have inevitably refined the notion of the problem into something more tractable and useful, better understood the nature of the system and of the people within it, and seen the value of storytelling as a means to cope with complexity. This focus on problem seeking helps the Policy Fellows to focus on what matters in changing the world and devise courses of action aimed at changing existing situations into preferred ones (Simon 1988).

Claudia Eckert and Kilian Gericke

Creating an ecosystem of design methods and tools

For decades, one of the raisons d'êtres of design research has been the creation of tools and methods for industry (Blessing & Chakrabarti 2009). There have been notable successes over the years. As a community, we have had a collective impact either directly through our research with industry or indirectly through our students. However, we find it difficult to evidence our impact beyond the positive and encouraging comments of our friends and contacts in industry (Mallalieu *et al.* 2024). It is often difficult to trace our tools and methods in industry practice, and it is a frequent lament that industry does not make use of our collective efforts.

Even if tools and methods are used in organizations, the impact of engineering design research is notoriously hard to evidence and measure, as much is aimed at avoiding mistakes. For example, our research on engineering change prediction (Clarkson, Simons, & Eckert 2004) aims to alert designers to the potentially catastrophic consequences of changes spreading through complex systems and direct them to less risky alternative solutions. Maybe we have saved engineering projects from great failures. Who knows?

There are many reasons why the introduction of tools and methods is challenging (Wallace 2011). Underlying them is often the same root cause: we think of the methods and tools in isolation. A problem is often identified in collaboration with industry experts and users, and a method is proposed to address this specific problem. This is then published or handed over, and the researchers move on. Methods fundamentally help designers to convert input into outputs through a set of steps. However, where the inputs come from, where the outputs go is often not explained, and how tricky steps are carried out is rarely explained in detail. This leads to users of the methods getting stuck and abandoning the methods.

We need to help the users of our research outputs by putting them into the context of the other methods, tools and steps that the organization is already using. Any new method needs to be seen in the context of an ecosystem of methods and tools that can be used in conjunction with what we are using (Gericke *et al.* 2020). As in a biological ecosystem, multiple methods and tools can operate in similar

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application areas and to some extent compete, but without suitable connections to and understanding of other methods, they either disappear without a trace or they damage or hinder other methods.

Looking at methods and tools in the context of an ecosystem also points to the sociotechnical nature of tools and method development in engineering design. To develop successful tools and methods, we need to understand not only the technical problems we are addressing, but also the cognitive, social and commercial context in which they are operating. This requires an interdisciplinary and holistic approach to engineering design research. The ability to bridge the social and technical is the greatest asset of this community, but also its greatest scientific vulnerability.

Fred Feinberg

Design science in 2025 and beyond: a project for humanity

People often ask exactly what Design Science is, and to me, nothing has captured it better than Papalambros' foundational maxim decades ago: "Traditional science studies the world as we found it; Design Science studies the world as we make it" (Frischknecht *et al.* 2009). Nature – often touted as the first and most ingenious designer – bequeathed humanity a planet filled with promise, wonder and danger, a primordial environment where we are component, not benefactor. Design Science aims at purposefully remaking that world so that humans can not only survive, but create, fulfill, plan and thrive (Buchanan 1992; Simon 1996).

My home field of marketing tells students to "find a need and fill it," which sounds easy on paper: just commune with those around us, and intuit what might make their lives easier and happier. But this leaves out the "Science" part of "Design Science": What exactly should we produce, and how many types? Can we provide something not only adequate, but durable, masterful, inspiring? And how does this all affect the local community and the environment at large in the future? (Michalek *et al.* 2011).

It has become a cliché to suggest we are at the dawn of a new era, but "Generative AI" has sprung forth to allow us to explore design landscapes of vast dimension in a world becoming "flatter" and facing accelerating global and environmental challenges. The question is no longer whether design matters, but how we engage its complexity *responsibly*. That is, Design Science is not just a methodological orientation or research program, but a civic and epistemic necessity.

In marketing, design used to play at best a supporting role, an aesthetic garnish on a functional offering that consumers will purchase at above production cost. Today, design *is* the offering. Experiences, platforms, algorithms and services are no longer just shaped post hoc by designers; they constitute the very value propositions firms offer. The aesthetic is now ethic, the interface the infrastructure. From this vantage point, Design Science studies how purposeful artifacts – material or conceptual – are ideated, developed and evaluated. But it is increasingly about how these artifacts structure interaction, shape markets and transform behavior. Consider the rise of AI-infused personalization systems, whose architecture requires engineering precision, artistic sensibility and consumer-centric psychological insight. These systems *design* consumers even as they are designed *for* them, a recursive dynamic is where Design Science is uniquely vital (Norman 2013).

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What has changed in the past decade is the velocity and visibility of this recursion. As design decisions increasingly shape not only individual choice but collective outcomes – from (mis)information flows to sustainability trade-offs – the personal and global stakes have risen. Design Science today is less about solving known problems and more about unearthing unknown ones, exploring their vast space of possibilities: framing, not just fixing. As our daily lives are increasingly shaped by algorithmically-mediated, designed environments that are dynamic, opaque and adaptive, Design Science creates the tools to make the invisible visible, to render consequential the seams between disciplines (Krippendorff 2006).

Ultimately, Design Science is not just an academic endeavor but a commitment to shaping collective futures worth inhabiting. In an age where every click, swipe and purchase embeds a design choice, the call is not just to design *better*, but to design *wisely*. That is a task no single discipline can claim alone, and Design Science will ideally provide a firm yet flexible agora for collectively productive exploration.

Sean Hanna

For those of us routinely engaged in computation, technological changes have always been a means to understand design, and while it was mentioned sparingly in the 2015 editorial as an important domain of research, artificial intelligence will almost certainly occupy our attention now. Much has changed. When Design Science launched 10 years ago, the game of Go was still safely the domain of uniquely human players. Machine translation, statistical more than neural, still produced laughable flubs, and fluent AI conversation was an aim of researchers, but far from day-to-day experience. These technological breakthroughs of the past decade are important, but even more is their ubiquity and ease of access, the impact of circa 2015 deep learning and facility with raw text and image data, which have made AI an integral part of our lives.

Among the "why?" of Design Science is the need to acknowledge how such changes in technology have indeed changed the practice of design, and to understand their effect. This is not something we can judge by intuition alone. The principle of Turing's (1950) test placed a human interrogator as the arbiter of intelligent behavior, their intuition and cunning sufficient to assess what the machine produces as output. Yet as we now see the Turing test passed for instances of design and creative output, we have to question our own ability as judges. In 1999, Douglas Hofstadter presented David Cope's computer-generated compositions, fooling experts at the Eastman School of Music into believing the machine was Chopin; his pessimistic conclusion was that the deeper experience of a human soul might be unnecessary (Hofstadter 2004). Could this be true? In my own field of architecture, generative AI can now produce a photorealistic image of a complete building. This too is convincing. But, at least for now, we can still recognize with deeper probing where the structure is incoherent, or that the spaces do not afford the sort of social interaction that is needed. In cases of design, it is precisely these deeper properties that matter most. More data and better-trained models will no doubt make more seductive and convincing images, but what will give us confidence in our ability to assess them? We may be poor judges of the Turing test.

Among the "how?" is a research method to correct our human judgment and to expand our point of view. Even if we design AI to be functionally equivalent to

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human intelligence (and to pass Turing tests) at the scales with which we are familiar, the details may be very different. Smaller than our usual experience, the understanding of neuroscience is needed to tell whether and how analogy, fixation and creative insight might be different in the brain. At the large scale are the ways in which we communicate and collaborate, perhaps via channels other than text and images and the impacts and long-term effects of what we design, all of which are far from obvious. These are all important because design problems are those that are complex, ill-defined, or what Rittel & Webber (1973) termed "wicked." The impossibility of formulating a clear definition of a design problem, or of foreseeing its emergent consequences, is what makes design such a crucial and rewarding human endeavor, and they are also what makes wicked problems such a challenge for traditional scientific methods. Controlled experiments very often miss the point. The clearly defined parameters outlined in the project brief are very often not the important factors of the design. At the moment, AI too is assessed and optimized for traditionally scientific outcomes, typically to minimize well-defined error, and is very likely to miss an important class of problems to which it might be applied. We are in need of a science that understands and is open to wickedness and complexity. This is what Design Science can be.

Katja Holtaa-Otto

What

Design science is the systematic study of design, where the word design encompasses the people doing the design, the act or process of designing and the artifact being designed. As an example, when focusing on people doing the design, it could be a study of how a designer constructs user understanding or empathy. When focusing on the act or process, it could be about a particular approach, such as comparing extreme lead users versus regular lead users as a source for potential latent innovative user needs. And, the artifact focus could be on, for example, the level of inclusiveness of the product.

Why

Design as a discipline has grown independently in many other disciplines but shares similarities across, making it a unique entity worth studying on its own. For example, user/customer/people-focused research has been present in many areas but often under a different name, such as human factors engineering, human–computer interaction, ergonomics, or requirements engineering. All have a goal of understanding the user to create a better solution, and thus it is important to develop an understanding of what all impacts constructing user understanding and how to best do it in different contexts.

In order to solve the so-called wicked problems, we need design. Design is problem-focused, and problems do not care what discipline you come from. We need an understanding of design itself. Design science is needed to accumulate knowledge and to build a proper theoretical understanding of design. This knowledge can then be packaged into specific design methods (Gericke, Eckert, & Stacey 2022) that form the practical path for knowledge transfer into practice.

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How

By using proper scientific methods, the same as in any scientific research. Design research can be theoretical, experimental, computational and so forth, just like any other field of research. Some of the weaknesses at the moment in design science include weak conceptualization and, consequently, operationalization of those concepts (Surma-aho & Hölttä-Otto 2022). For example, there is no general agreement on what empathy is and how it should be measured. Similarly, there is no general consensus on what creativity is, modularity, or many other concepts in design, and how they should be measured. This is even though each of these areas has decades of research. Instead, researchers tend to develop their own metrics to measure something they are interested in (Eisenmann *et al.* 2021). This prevents comparison of approaches, building on past knowledge and thus the accumulation of knowledge and advancement of the field. This design science needs to take advantage of the full spectrum of scientific methods, starting from clear definitions of concepts.

Marija Jankovic

Designing is an inherent human activity that has characterized and enlightened human society since its beginning. John Gero (Papalambros 2015) has underlined that the discussion of design spans over thousands of years (he cited the Epic of Gilgamesh and the Code of Hammurabi). However, as a science, it has been developed after the Second World War and has been discussed ever since.

The contributions of the first editorial (Papalambros 2015) proposing to discuss research direction in design science were considerable. If one looks at it, very much of these discussions have actually been tackled, and some are still ongoing, underlying the richness and precision of proposed directions. Many have cited the focus on design process, people/collaboration and organizations. This research is still very much relevant as new forms of design activities emerge using novel technologies and social networks. It has been underlined that the future of design science lies in enhancing the rigor in research methodology and in developing more scientifically grounded methods. Several propositions in the research community have been discussed and contributed to the soundness of the produced knowledge and conclusions (Eckert, Clarkson, & Stacey 2003; Blessing & Chakrabarti 2009; Vermaas 2022). The difficulty is related to the interdisciplinarity, multidisciplinary (crossing boundaries between disciplines or transdisciplinary (borrowing research methods and theories from other disciplines) of the design. The current discussions have contributed both to the clarification, but also need further development in the community to have an established research methodology body of knowledge. Moreover, numerous contributions also suggested that the design research will evolve from designing manufacturing products to novel concepts of "products" spanning from business models, services and policymaking. And, as underlined, it has been an interesting period addressing data collection (Cantamessa *et al.* 2020; Rahman *et al.* 2020), impact of IoT in design and artificial intelligence (Shabestari, Herzog, & Bender 2019; Chen *et al.* 2025).

In my view, the interesting aspect of the design research that has been highlighted by different researchers (Papalambros 2015), but is even more relevant today, is that the design research is focusing on predictions, on creating possible futures and possible scenarios. Today, with increasing challenges pertaining to

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climate change and sustainability, the research in design sciences can significantly contribute to both scientific and societal orientations on different levels. The first one concerns the *integration of constraints pertaining to sustainability*, such as continuing to develop methods and tools in eco-design or Design for Sustainability. The second level is to understand *the design activity in a larger context*, such as the *circular economy*. In this context, not only does the design need to support reuse or remanufacturing and consider these constraints in design, but also, we need to research how we can support the design of these new industrial (socio-technical) systems with the objective to support sustainability directives and goals, integrating the needs and social aspects such as equality. The third level, in my opinion (although not the last one), is to *design new societies* concurrent with new economic models. In this sense, investigating possible futures/scenarios to guide future developments regarding possible economic models could be an interesting contribution of our scientific community and discipline.

However, even though previously discussed strategies are key to achieving sustainability objectives, it is important to realize that the redesign of societies cannot be done by one single discipline. I believe that the accumulated experience and research methodology in design science can be an inspiration to further bridge knowledge across disciplines such as Climate change, Economy, Policy-making and Supply Chain Management, to investigate and evaluate these possible scenarios and possible futures.

Roger Jiao

Reflections in the context of engineering design

Why: Design science is essential as it offers a structured, systematic approach to understanding and refining design processes (Hatchuel *et al.* 2018). Within a journal context, it involves the rigorous investigation of design principles, methodologies and their applications to generate academically sound knowledge (Papalambros 2015). This highlights its emphasis on design research rather than solely design practice or domain-specific implementation. Unlike purely artistic or intuitive approaches, design science focuses on creating knowledge that enhances efficiency, fosters innovation and advances problem-solving across disciplines.

Generality is a fundamental trait of design research, ensuring that findings extend beyond specific cases to contribute to broader knowledge. A well-conducted design study allows its principles to be applied across similar domains. In this regard, design science acts as a bridge between theory and practice – uncovering the underlying rationale behind best practices to transform creative concepts into structured, repeatable and evidence-based methodologies. Through systematic analysis, design science enhances problem-solving and refines the development of products, systems and experiences. It plays a critical role in optimizing complex systems and fostering innovation, empowering researchers and practitioners to explore new methodologies, streamline workflows, drive technological advancement and improve design efficiency.

What: Given the inherently contextual nature of design, it is essential to examine the "What" dimension of design science in relation to its working subject – specifically, the problem context. Like any scientific research, hypothesis testing is a fundamental aspect of design research, where establishing a meaningful problem context is paramount. Compared to the traditional focus on mechanical

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design, contemporary engineering design goes beyond isolated product development, encompassing product industrial realization within an extended enterprise (Jiao *et al.* 2022). Engineering design encompasses the entire spectrum of product realization within an extended enterprise, integrating engineering, manufacturing, supply chains and value networks to ensure seamless and holistic coordination across disciplines.

Engineering design has evolved into a complex and multidisciplinary discipline, shifting the product creation horizon from a physical artifact-centered approach to a holistic life-cycle experience, enacted through cyber-physical-human and sociotechnical systems. Product design is no longer limited to hardware; rather, it emerges through the co-design of an interconnected product ecosystem. This ecosystem coordinates product fulfillment, services, experiences and human satisfaction at both individual and community levels. The artefact aspect of design extends beyond physical products to include service and digital products. Its scope spans the entire product realization lifecycle, encompassing areas such as supply chain design and the development of product-service systems.

How: Scientific research is grounded in several fundamental traits that ensure its rigor and reliability. A crucial aspect of design science that warrants emphasis is verification and validation (V&V). While definitions may vary, Jiao *et al.* (2021) assert that "*validation is to make sure that our research is doing the right thing, whereas verification is to justify to what extent our research is doing things right.*" Design problem-solving inherently involves a what-to-how mapping process (Suh 2001), where validation pertains to the what aspect (i.e., problem formulation), while verification addresses the how (i.e., methods or solutions).

Similar to computational studies and algorithm development, benchmarking and performance comparisons are commonly used for design verification. For instance, evaluating objective functions using the same dataset or numerical example helps assess the extent to which a proposed design optimization model outperforms alternative methods in solving similar problems.

Ensuring validity – particularly in terms of the motivation and significance of the problem context – is a challenging aspect of design research. Formulating a meaningful research problem that closely reflects real-world conditions is essential for plausible validation. Field studies, rather than relying solely on hypothetical or numerical examples, help anchor research in practical contexts, ensuring its relevance to industrial applications.

For design science, explicit industry relevance and concrete engineering contexts are vital for conducting meaningful and rigorous sound design research.

Yan Jin

Ten years ago, *Design Science* was launched with the goal of articulating and promoting a scientific foundation for design. In the inaugural editorial, I outlined a vision grounded in understanding the interplay among purpose, artifact and environment, mediated by the behavioral and physical dimensions of design activity. At the time, there was skepticism about whether "design science" could exist as a unified and coherent discipline. Today, we reflect with pride on the progress made by our authors, reviewers and readers who have collectively contributed to making design science a recognized scholarly discipline.

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Over the past decade, our journal has published a wide range of research exploring fundamental questions at the heart of design. Significant strides have been made in elucidating the behavioral aspect of design, how sociological and psychological factors shape the designer's actions, decisions and creativity. At the same time, investigations into the physical aspect of design have deepened our understanding of the artifact-environment interface. Collectively, this work has advanced theoretical models and practical tools that address the essential mappings between purpose and artifact, as well as between artifact and environment.

What was once a fragmented body of design knowledge across disciplines such as engineering, architecture and industrial design is now beginning to coalesce into a more integrated field of study. A behavioral-physical framework has helped unify research directions, providing both a physical vocabulary for composing artifacts and a behavioral foundation for training effective designers.

However, as we celebrate this progress, we also face a transformative shift in our intellectual landscape. The emergence of artificial intelligence, particularly generative AI and large language models (LLMs), has begun to redefine the very nature of knowledge-based brainwork. These technologies offer new capabilities in ideation, simulation and problem-solving, accelerating many tasks traditionally performed by designers. The impact is profound: designers are no longer merely problem solvers; they now assume the role of orchestrators, directing a distributed network of AI agents toward shared design goals.

This paradigm shift introduces critical new challenges and opportunities for design science. At the intellectual level, research must now address the dynamics of human–AI collaboration. We see three pressing areas for inquiry: (a) How can human creativity be effectively leveraged in environments dominated by AI augmentation? (b) What models best describe human–AI, AI–AI and human–human interactions in collaborative design processes? (c) How does knowledge evolve in these hybrid teams, and how can we ensure that this evolution leads to socially beneficial outcomes while mitigating risks?

These questions demand a renewed agenda for design science, one that embraces complexity, fosters interdisciplinary thinking and places a strong emphasis on ethical and epistemological considerations. The human designer remains central, but their role is changing. As curators of purpose, stewards of creativity and directors of AI agencies, designers must now master not only their domain but also the orchestration of intelligent systems or AI agents.

As we mark the 10th anniversary of *Design Science*, we look ahead with both excitement and a sense of responsibility. The next decade promises even greater challenges and opportunities in the realm of AI. Together, we must continue to grow the "interface" Herbert Simon spoke of: the interface where natural and artificial systems meet, evolve and co-create. This is where the future of design science lies.

Maaike Kleinsmann

The world today stands at a critical juncture, shaped by the impacts of climate change, shifting geopolitical forces and persistent global health challenges. These intertwined crises demand urgent societal transitions across energy systems, urban planning and (public) health infrastructures and services. While technological innovation offers powerful solutions – from renewable energy to smart digital

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healthcare solutions and resilient infrastructure – its effectiveness hinges on more than technological change. To get these innovations adopted, we also need deep social changes on different system levels, such as behavior, work systems, policy and public values.

We all know that Design could serve as a vital connector between technological innovation and social change because it is inherently an integrative and transdisciplinary discipline. Faced with complex, "wicked problems," Design offers a constructivist, iterative approach that embraces uncertainty, surprises and unintended outcomes as part of the process. Design has a profound understanding of working co-creatively with diverse stakeholders, allowing problems and solutions to co-evolve during the process and to imagine possible futures through prototyping. This openness to emergence and situated feedback of the situation makes design *uniquely suited* to navigate the messy, dynamic terrain where technology and society intersect in times where socially meaningful solutions are essential.

Having shown the profound role Design can play in societal transitions, it is important to acknowledge that the field's actual impact could be increased. To bridge this gap, we – as a design community – must also critically revisit and redesign some of our own (research) practices. Let me name three areas that deserve attention. First, *transdisciplinarity*. While design has a strong tradition in multidisciplinary teamwork and co-creation (mainly stemming from product design practices), true transdisciplinary impact in societal transitions requires alignment with the standards of the domains we operate in. For instance, in healthcare, meaningful change depends on working with established knowledge frameworks – making activities like literature reviews an essential part of the design process. Second, *evidence*. While Design has built credibility on evidence generation in areas like engineering, usability and human factors, it lags in generating robust evidence for system-level change and the effectiveness of our approaches. Such evidence is critical in convincing stakeholders and decision-makers to adopt our solutions in complex domains. Third, *implementation*. Although Design has historically excelled in prototyping and production processes, we need to deepen our focus on how solutions for transitions are adopted, modified, scaled and sustained over time. Especially in transitions, implementation is not the final step but a continuous process that requires Design's full attention and creativity.

Design Science is *the* design journal to pick up these new design research practices, as the journal's focus is on science-based design knowledge across multiple disciplines. By embracing elements from this agenda, the journal can help catalyze a shift in how design contributes to society – by producing innovative concepts together with rigorously demonstrating their value, scalability and relevance across complex domains. In doing so, we position Design as a driving force in shaping more sustainable, equitable and resilient futures. And I am looking forward to contributing. Happy anniversary, Design Science!

Terry Knight

What is "design science"? I interpret this phrase today as I did in my editorial 10 years ago. In the spirit of Nigel Cross's (2001), p. 53 distinction, I take "design science" to mean the science – or study – of design, not design as a science or as a scientific enterprise (a narrower idea). And I understand "design" in an equally broad sense, similar to how design was defined by Herbert Simon several decades

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ago as "courses of action aimed at changing existing situations into preferred ones" (Simon 1996, p. 111). Simon viewed design as an activity common to all the professions, from engineering and architecture to business, education, law and medicine. He did not include the natural and social sciences or the humanities. Today, however, many in those disciplines would argue that they, too, engage in design. With rising awareness in academic and industry contexts of the value of design, views of "design" have become more expansive and inclusive. For example, the Morningside Academy of Design at MIT, where I work, lists as design courses courses not only in the expected places (for instance, architecture and mechanical engineering), but also in chemistry, biology, mathematics, anthropology, history, music, theatre arts, linguistics and philosophy.

Over the past 10 years, the many papers published in *Design Science* reflect this expansive perspective. The study of design in all of its manifestations, which this journal has promoted, is critical to advancing awareness of the impacts of design for society – its potential to create delight and well-being and to solve problems across multiple domains. However, as design becomes increasingly multi-disciplinary, it is increasingly important to study and affirm design as a field in its own right, a field with its own history and body of knowledge, and with uniquely variable methods from objective, rational and systematic to fluid, improvisational and indeterminate, each rigorous in its own way. *Design Science* papers have represented this breadth of approaches.

Importantly, design is an essential, universal human activity that demands and reveals core human capacities: social, intellectual, physical, cognitive and perceptual. Design thus sits as one of the biggest challenges to the inescapable topic today – AI. It challenges potentially inherent limitations of artificial intelligence and exposes what makes us human. I rejoice in that, both because I like a challenge and because I am in awe of what people can do and what AI has yet to come close to. In my own work, I take an algorithmic, generative approach to design with shape grammars and making grammars. But in contrast to Generative AI – an algorithmic, machine-driven enterprise with creative aspirations in design – I call my course at MIT "Generative HI," generative human intelligence. The creative design work we do by hand, eye and touch with grammar is beyond what my very tech-savvy MIT students can automate easily or at all on a machine. We learn to appreciate what is human about design.

I hope that this knowledge contributes to the collective and varied efforts of many others working to advance the study of design.

Pascal Le Masson

Uncovering the logics of generativity with design theory, a contribution of design science to the community of scientific disciplines

Design science for the broader scientific community

A scientific discipline contributes most to the wider scientific community when its results are as universally relevant as possible. Just as physics is not only for physicists, design science is not only for designers.

This is particularly true for design science, as design is a fundamentally universal activity. It is practiced by a wide range of professionals – engineers, architects, industrial designers, artists, scientists, managers, policymakers – and is present across numerous disciplines, including engineering, management,

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agronomy, life sciences, mathematics, physics and philosophy. At the same time, design is both expected and critiqued by societies grappling with major contemporary challenges. This gives rise to a critical and ambitious goal: for design science to produce universal results that enhance the design capabilities of all.

This ambition was central to Herbert Simon's program in The Sciences of the Artificial, which sought to establish design science as a rigorous and general discipline, comparable to decision science. His vision helped launch a collective effort that includes many initiatives, among them the founding of the Design Science journal ten years ago.

Design theory: capturing the logic of generativity

It is well acknowledged that Simon's program was "unfinished" in terms of design theory (Hatchuel 2001). One major line of work has been to renew design theory to better account for generativity – the capacity to produce new, valuable propositions from available knowledge. This has led to the foundation of a new paradigm for design science and engineering (Hatchuel *et al.* 2018). Advanced design theory, such as C-K theory, has demonstrated "unique features" (Sharif Ullah, Rashid, & Tamaki 2012), allowing scholars to move beyond commonly misleading analogies (such as abduction, decision-making, or creativity) and to more accurately model strong generativity.

Design theory is increasingly featured in Design Science publications, helping to construct hypotheses, refine analytical frameworks and produce robust research outcomes. Even more noteworthy, it has had a tangible impact across various disciplines and professions. One among many examples is its application to teaching biomimicry (Nagel *et al.* 2016), illustrating how design science can foster breakthroughs in other disciplines.

Today, design theory is well-positioned to help analyze, interpret and guide the development of critical emerging technologies like generative AI (Chen *et al.* 2025). It also provides essential tools for tackling the challenges of designing for sustainable and societal transitions (McMahon, Subrahmanian, & Reich 2022).

The future of design theory: an integrative language for transitions?

Recent advances in design theory open exciting opportunities to further develop design science for transitions – toward creative preservation (i.e., non-Schumpeterian innovation), enhanced generativity with data and large language models and the co-design of socio-bio-ecosystems. Design theory offers sharper tools for analysis, observation, modeling and experimentation – meeting the high standards of the Design Science journal.

Conversely, design theory must continue to evolve to fully address contemporary challenges of generativity. To become an increasingly effective integrative language for both disciplines and practitioners, it may require the use of abstract, formal and mathematically grounded constructs – subject to rigorous evaluation by the Design Science journal community.

We must also recognize the tension between the abstract mathematical formulations now needed for advanced design theory and the imperative to make contemporary design methods accessible to a broader audience beyond design science experts. Other fields, such as theoretical physics and, to a lesser degree, decision theory, have faced similar tensions in their development. Their histories

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teach us that successful disciplinary growth depends on organizing high-level, transdisciplinary knowledge transfer – and even knowledge creation. We hope that the Design Science journal will continue to serve as a crucible for this kind of constructive, transdisciplinary dialogue.

Kemper Lewis

If the first 10 years of design science were about establishing the foundation and defining the contours of the field, then the next ten will be about transformational influence. Leadership, at its core, is the ability to influence outcomes – and design science is uniquely positioned to lead. No longer just a problem-solving discipline, design science must evolve into a future-shaping force. It holds the potential to architect systems, guide behaviors and shape narratives in response to the world's most urgent technical and social challenges.

Realizing this potential will require a convergence of technological, societal and methodological shifts and will demand a deeper integration with emerging technologies. Critical to our future success will be a more pronounced and partnered role in addressing complex problems once deemed intractable. The design science community must not only participate in these shifts – but lead them. Some of the critical areas where design science must take a leadership role include:

- Viewing AI, machine learning, generative models and quantum computing as both designed artifacts and design tools (Chen *et al.* 2025).
- Creating platforms for researchers and practitioners to co-design with intelligent systems in the face of complexity.
- Prioritizing and codifying ethics-aware algorithms and responsible design innovation.
- Expanding our influence into socio-technical systems design, including digital healthcare, urban systems, personalized education and public policy.
- Reimagining the historical tension between academic rigor and practical relevance by bridging more engaged scholarship models and actionable design science.
- Broadening design impact by building mid-range theories of design grounded in empirical work but abstracted for generalizability.
- Advancing design analytics to be able to trace design decisions through data and objectives, enabling more transparent and reproducible research.
- Exploring the engagement with Global South perspectives, local knowledge systems and non-traditional design disciplines (Fry 2017).
- Evaluating who benefits from designed systems and in what ways, and how power dynamics shape both the design and use of systems.
- Fostering of stronger institutional support with new centers, curricula and doctoral training programs that formalize design science as a core research domain.

The next decade of design science must be marked by finding solutions to seemingly contradictory paradoxes (*Lewis & Smith 2023*). We must remain timelessly grounded in theory, design logic, decision sciences and methodological rigor, which are capable of shaping timely solutions to some of the most pressing challenges of our time. We must create deeply personal design solutions while also being inherently collective and able to scale for wide impact. We must continue to

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press for establishing design science as a necessary bridge between wickedly complex problems and beautifully elegant solutions (Lewis 2012).

Julie Linsey

Design is an inherently complex endeavor that demands input and engagement from multiple cultural and disciplinary perspectives, as well as highly varied skill sets, in order to be highly successful in a predictable manner. The science of design, too, demands the transcendence of multiple fields, which ultimately must fuse disciplinary boundaries and perspectives, while also addressing and improving existing disciplinary biases. To effectively accomplish this, a deep knowledge of multiple fields is often required. This can be observed within design research as academics from multiple fields collaborate and harmonize their approaches to meet the needs of design research. Very often, the doctoral students integrated in these collaborations gain the research methods and deep knowledge in both fields, pushing design research forward in very innovative ways due to their deep and integrated knowledge.

Design research has made significant strides, but it remains a complex science, with much more needing to be done. Here, I choose to focus on a few high-impact issues that I believe require more attention and space to innovate. This is by no means an exhaustive list of important areas.

The design science community continues to face daunting challenges in the research methods we employ and the impact we desire to have. The research approaches necessary to answer the very complex questions of design science require the community to continue integrating methods from other fields and developing them to better meet the needs of design research. There is a continued need to push the existing tools and methods to better meet the needs, while broadening what is being leveraged and adapted. This forces constant learning of new approaches while also demanding space within the community to be open-minded about "how" research should be done and what qualifies as high-quality research. Friendly discussion, debate and clarification are healthy in this context, but can be extremely challenging to promote. If paradigms of research are constantly being borrowed and developed, it becomes harder for the community to identify high-quality research, but we have little hope of achieving great success if we do not attempt to do this. This also means attempting to push both the quality of research can be in psychological conflict with continuing to broaden the methods and metrics.

There have been numerous attempts at pushing innovation with much success and learning. These range from special sessions at conferences, publishing conference papers intended to promote discussion, special journal issues and others. I do believe that we as a community need more small experiments on how to support, scaffold and develop more innovation in our methods, approaches and metrics. It may be single experiments with special journal issues with a novel review process, a virtual discussion group, or something completely different. More needs to be experimented with and learned from. Many different options are possible. Inspiration should certainly be drawn from other innovative communities.

Leveraging multiple methods and triangulating the results is another area that will help make great strides. Triangulation of methods and the use of multiple methods to gain insights hold tremendous promise, but are also very challenging to

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implement, as the results may be conflicting, include different measures, and often span different levels of control and validity. Often, this is something that will occur across multiple dissertations and not within a single piece of work. I do realize how extremely challenging it is to align multiple studies over a number of years and across different research paradigms. Also complicating this is that there are very few examples of how to do this well. More studies that evaluate the same phenomenon in a range of settings, from highly controlled laboratory experiments with large sample sizes and often students, to more realistic settings of competitions and longer-term projects, and finally to real-world settings, are also needed.

Research with industry or in more realistic settings is non-trivial, but tremendously valuable. Many of the methods, like controlled laboratory experiments, do not transfer seamlessly to an industry setting and there are many aspects that make the research even more challenging and time-intensive. The first major challenge lies in obtaining access to professionals and finding willing organizations. Intellectual property agreements between the university and the company are often needed. Real-world settings often pose more confounds and unexpected changes, from participants suddenly needing to leave a session, to studies being rescheduled, to industry desiring much faster implementations and results than what is typical in academia. Further adding to the mosaic of barriers for design research in industry, there is a corporate culture and ways things are typically done within an organization, which is often hard to quickly understand or capture within a study. Additionally, individuals have often, over the years, developed ingrained and somewhat optimized approaches for the work they do, which can make it much harder for them to change their work processes as needed for a study than for students who often lack much of an ingrained approach.

More also needs to be done to engage the industry and disseminate design research to them. A greater understanding of the successful dissemination pathways must be sought, along with an understanding of the needs of industry and other organizations. How can design research better collaborate with and help industry, government and various other agencies in improving the human condition and address the grand challenges the world is currently facing? What can academics do to better answer the needs of industry and increase the practical impact of our work?

While a complex and challenging endeavor, design research must continue to innovate on the approaches used, seek to answer the complex questions within industry and other organizations and pursue high-quality research.

Jianxi Luo

Design science: shaping a human-led future

Design is the deliberate creation of novel, useful artifacts – materials, structures, systems – that transform our world and advance economic and social well-being. Unlike the slow, undirected process of evolution, design is rapid, purposeful and cost-conscious, harnessing knowledge, creativity and tools (Dennett 2015). Design science, the scientific study of design, investigates how artifacts are created, how designers think and act and how these interact with natural and societal environments. While design itself need not be scientific (Cross 2001), design science provides a rigorous framework to understand and enhance it.

https://doi.org/10.1017/dsj.2025.10026 Published online by Cambridge University Press

Humanity's mastery of design has driven four industrial revolutions: mechanization, electrification, digitalization and now intelligentization. The Fourth Industrial Revolution (4IR) marks a transformative era where intelligent technologies we design – AI, autonomous systems, genome editing – blur boundaries between cyber, physical and biological realms. These design innovations pose complex sociotechnical challenges, such as ethical dilemmas in autonomous decision-making, risks in genetic engineering and AI-driven misinformation (Schwab 2018). Traditional heuristic design methods are inadequate for addressing the 4IR's complexity.

Designers must adopt holistic, sociotechnical approaches that embed core human values (such as equity, justice, privacy) and "ilities" (such as reliability, sustainability, evolvability) from the outset. This requires navigating intricate system-of-systems ecosystems where stakeholders collaborate and compete. Designers need high-order, high-dimensional empathy and creativity to tackle sophisticated problems, embracing unpredictability through "evolutionary ecosystem design thinking" (Luo 2023). AI, with its acquired knowledge and advanced reasoning, augments human empathy and creativity to tackle 4IR challenges, fostering innovation among diverse actors to ensure solutions are adaptive and inclusive. Yet, human leadership remains essential to steer AI as a tool in the design process, ensuring alignment with human values and preventing unintended consequences.

As design, AI and AI for design grow more complex, design science must evolve as a transdisciplinary meta-science, bridging theory and practice across academic disciplines and practical domains. It embeds ethical and sustainable principles to tackle 4IR challenges. Design science breaks ambitious goals, such as circular economies, into manageable systems. It leverages AI to understand human needs, generate and optimize solutions and prioritize social equity. Fostering stakeholder engagement ensures solutions are scientifically robust and socially accepted.

Design science stands as the cornerstone of a human-led future in the 4IR. Through systemic thinking, transdisciplinary collaboration and accountable innovation, it harmonizes 4IR's emerging technologies with humanity's needs. By embedding empathy, creativity and rigorous methodologies, design science ensures AI-driven design aligns with sustainable development goals, shaping an equitable, resilient future where technology enhances well-being, sustainability and justice – guided by humans, not algorithms.

Chris McMahon

Congratulations to the DSJ on a very successful first 10 years, and thanks to all those, especially the founding editors, whose vision brought the Journal to fruition. Thanks also for the splendid initiative of asking for new reflections on the "why, what, and how of design science."

Ten years ago, I wrote, reflecting on the enormous challenges humanity faces in this 21st century, that we need to learn new ways of designing that are less dependent on incremental development of existing solutions, and that we need to be bolder in our ambitions for change. The intervening years have made the predicament that we face from the environmental impacts of our artefacts even

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clearer, and the needs more urgent. And although big strides have been made, we have a long way to go in understanding the direction we must take and in convincing the world of this: for all we have learned, the actual impact of our research on the design decisions made by our societies is limited. These considerations help us answer "**why** design science" – at best, in the absence of a good understanding of the fundamentals of design and application of that understanding, we risk underperforming artefacts and design processes that are more protracted and expensive than they need to be; at worst, we will simply be unable to navigate out of the predicament that we face.

Ten years ago, I also wrote that **what** we need is a collection of knowledge, tools, methods, processes and understandings that enable the confident definition of artefacts, be they physical constructions and products, systems, or services. I saw then the need for new ways to capture, document and disseminate design knowledge; to improve our understanding of the gaps in our method portfolio, and, where we have methods, to better match problem to approach; I suggested then that we need to ask how can we learn from the very extensive data that we have about the performance of artifacts and the tools used to design them, and that we need to be able to advise on the time and resource implications of realizing these. I believe these are all still important areas needing attention, but increasingly I believe we need to return to fundamentals and ask if we have them correct. What is the relationship between design and technology, and between design science and the engineering sciences? Do we have an adequate theoretical understanding of design, and does our theoretical understanding properly inform our research and the advice that we can offer concerning good design practice? What would a top-down view of design, starting with the role of engineered artefacts and systems in the Earth system, and taking due cognizance of the impacts of artefacts on that Earth system, tell us about the directions we should take? Do we need to be more discerning in our choice of technologies in the light of those impacts? This is a good time for us to revisit these and other questions.

As for **how** we conduct it, I suggest that we should be both more outward-facing and more inward-looking. Facing out from the community, I would like us to be much more active in using our knowledge to advocate for action by our societies, using our insights about the nature of design to inform political and commercial decisions about the design of the engineered systems that form the artificial world in which we live, and to advocate for change (McMahon, Subrahmanian, & Reich 2022). Looking inward within the community, I would like to see much more cross-fertilization of ideas and insights: especially a greater role for design theory in our research, for example, in categorizing methods and tools, in motivating experimental studies, and informing the development of design tools, particularly the digital tools that are so pervasive today.

I wish all in the community an exciting and productive next 10 years!

Yukari Nagai

Do not miss the real life and nature of design creativity

Warm regards to the editors and congratulations to everyone involved with Design Science on their tenth anniversary. It was a big challenge to develop the field of design based on discussions and establish our position in the history of science. This field is still progressing, and we have a long way to go.

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Personally, my biggest challenge was to identify the power of design by investigating human creativity (Nagai 2016). Several questions were raised, such as “What is the nature of design creativity?” “Why do we want to create designs?” and “How can we foster design creativity?” These questions are critical in enhancing design creativity and creating a sustainable society.

Surely, no one can design alone. Co-creation is an essential aspect of design creativity; however, the concept involves plural synthesis and combinations of the self and others. For example, “we” are “you” and “combinations of you” at the same time, and “we” can also be “she,” “him” and “them.” Though it may seem like it, this is not a word game. In other words, no one can capture our world. To understand the concept of design, I proposed questions on individual creativity that draw on the meaning of people’s lives. However, I still have not been able to find an answer.

Designing is a fun and enjoyable activity, yet one must approach it with care and consideration. The OECD Learning Compass 2030 is a learning framework that shows that the Anticipation-Action-Reflection (AAR) model is central to learning (OECD, n.d.). People are represented as agencies, and discussions should be fostered among communities. When I saw it, I understood that their competencies represented design creativity.

We can talk to others about our hopes for the future and understand each other well. This makes it easy to collaborate and co-create something. Experiencing the meaning of design through co-creation brings joy. However, we cannot approach the essence of design without ignoring the fact that the world – that is, real human society – is divided. Humanity has caused this divide, based on the needs of each human society. Though such a strict perspective is not required in individual research in design science, after 10 years, I think it will be good for researchers to not only reflect on their achievements but also consider the issues that are beyond their reach, which will positively impact the next 10 years’ research. Thus, it is necessary to keep Design Science up-to-date and encourage high-quality discussions. It is equally important for us to have the courage to face criticism and difficulties.

“Innovation Design,” which means social creativity, is another research theme of DSJ. While innovation is a popular term in all domains of science, the ways of designing innovation are still unclear. I am currently one of the 105 members selected as part of the Science Council of Japan (SCJ), a representative organization of the Japanese scientist community that encompasses all fields of science, including the humanities, social sciences, life sciences, natural sciences and engineering. As a member, I have contributed enthusiastically to the council. Through my work in SCJ, I realized that no one knows the real power of design or the meaning of creativity among them (scientists of traditional domains). In fact, SCJ is being negatively affected by political power. I recommend that every scientist read Design Science to reframe science and the scientific community.

I wish Design Science the best of luck and look forward to its continued development and achievements.

Daniela Pigosso

Design science as the pathway to absolute sustainability

Design science has a fundamental role in shaping how we understand and address sustainability challenges. As humanity faces unprecedented ecological crises, there

https://doi.org/10.1017/dsj.2025.10026 Published online by Cambridge University Press

is a growing need to design products, services and systems that remain within the Earth's ecological boundaries. This editorial article explores the *why*, *what* and *how* of design science in the context of sustainability, focusing on the critical shift from relative to absolute sustainability.

Why

The primary reason for the urgency of design science in sustainability is the pressing global challenges we face. While life cycle thinking revolutionized sustainable design in the 1990s (Hauschild 2015), the implementation of this approach has yet to deliver the expected results, with many planetary boundaries already surpassed (Richardson *et al.* 2023). The impact of traditional environmental design strategies, focusing on efficiency-effectiveness-sufficiency, has been insufficient due to rebound effects (Pigosso 2024). In response, we need to shift toward design strategies that foster absolute sustainability, a paradigm that aims to design systems and products that do not exceed the Earth's carrying capacity (Kara, Hauschild, & Herrmann 2018).

What

Design science offers a methodological framework for creating innovative products, services and systems that enhance the environmental, social and economic impacts of human activities. Through its interdisciplinary approach, design science is essential in preventing the negative consequences of interventions, particularly those arising from behavioral and systemic changes, ultimately driving meaningful, global transformation.

To achieve this, design science must adopt systemic thinking and a holistic perspective, incorporating socio-technical systems, policy and human behavior. It should move beyond the objective of merely developing "less harmful" solutions, aiming instead to design systems that are not only effective but also "good enough," remaining well within the planetary boundaries.

How

To address the sustainability challenges, design science must evolve to incorporate principles of absolute sustainability. This includes focusing on the design of systems that not only improve efficiency and effectiveness but also address sufficiency and prevent rebound effects (Pigosso 2024). The *how* of conducting design science involves:

- Systems Thinking: emphasizing the interconnectedness of economic, environmental and social factors, while considering the broader systemic impacts of design interventions.
- Reboundless Design: Developing methods to prevent the rebound effects that arise when improvements in one area lead to negative consequences elsewhere, due to behavioral and systemic changes.
- Fostering Absolute Sustainability: Moving beyond relative improvements to ensure that products and systems stay within the Earth's carrying capacity.

Design science in sustainability also requires an ongoing dialogue between researchers, policymakers and industry practitioners. Such collaboration helps

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ensure that design interventions are not only scientifically sound but also socially and economically viable.

Conclusion

Design science is pivotal in transitioning to absolute sustainability, capable of addressing the global challenges within the planetary boundaries. By incorporating systems thinking, preventing rebound effects and fostering absolute sustainability, design science offers the tools and methodologies needed to create lasting, impactful solutions. As the world continues to face growing ecological pressures, the development of design science for sustainability will be essential for achieving global absolute sustainability goals.

Yoram Reich

Design science's "*why*," "*what*," and "*how*" are missing a critical companion – "*who*!" Any design activity is performed by some "*who*" and must start identifying its stakeholders. Only with them can a design challenge be understood and framed, again by actors. When these actors understand the challenge as it evolves, they can assemble a team to address it. The stakeholders and the team participants respond to the question "*who*" in a design challenge. It is also easy to discern the missing "who" question following design theory, for example, from the PSI (problem-social-institutional) framework and theory of design (Reich & Subrahmanian 2020), which demands that the problem space (representing the *why* and *what* of a challenge), the social space (representing the *who* is involved in solving the challenge) and the institutional space (describing *how* those involved address the challenge) must be aligned for the design to succeed. The same holds for journal management, research activity, design theory, or design science.

So, who are the stakeholders of design theory or science? Recently, we developed a model for design theory value that includes articulating these stakeholders (Reich, Lavi, & Shoham in press); they include:

1. Design scientists and their teams and organization infrastructure, which we term the enterprise.
2. Design professionals (in organizations) who employ theories or other design scientists, whom we call customers.
3. The society that is paying for the theories and is interested in enjoying the products developed using them, referred to as society.

Each stakeholder has its own objectives and derives different value from a design theory. Those designing theories are tasked to provide value to these stakeholders, even if they focus on part of them. In such a case, it should be clear who the target stakeholders are. For example, one can hardly claim value for customers when conducting laboratory experiments to validate a theory – one cannot play 20 questions with creativity, innovation, or design and win (Reich 2022). Understanding the value of design theory to stakeholders and how to leverage this in design research practice should be central to design science.

The second question is how to involve these stakeholders in design science so that the products of our endeavor maximize their value. Several means could be exercised, including:

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1. Inviting representatives of design organizations or society to write position papers specifying critical needs for new theories or present how they view and use design theories. This is practiced well in the meetings of the Design Theory SIG of the Design Society, where practitioners such as chefs, wine makers, architects and other practitioners, as well as researchers from diverse disciplines, including biology, astronomy, management and philosophy, share their experience and insight.
2. Encouraging the participation of diverse stakeholders in design research. This requires the means and expertise to organize large-scale transdisciplinary projects, develop mechanisms for distributing credit and ownership to participants and provide incentives to participate.

If we address the "who" in design science, we will use diverse perspectives and transdisciplinary knowledge to develop better design theories that provide more value to their stakeholders; if we do not, it is unclear who will benefit from design science.

Tahira Reid

Design science as bridge and beacon

Design Science offers a unique approach to framing and solving problems. At its core, it involves the "creation of artifacts and their embedding in our physical, psychological, economic, social, and virtual environments." While much of the discourse focuses on how design science impacts design itself, its foundation supports problem-solving far beyond the realm of product or service design.

As the first graduate of the University of Michigan's Design Science program – where I combined methods from psychology and mechanical engineering – I have seen how this foundation, paired with personal curiosity, has shaped much of my career. When I started my research lab, my goal was to truly address design problems, particularly by bridging customer evaluations and design decisions. In graduate school, my work relied mainly on self-report data. As a postdoctoral fellow, I added eye-tracking. When I launched my lab, I expanded further to include psychophysiological measures such as galvanic skin response and electroencephalography. These tools allowed me to triangulate data and gain a deeper understanding of human responses during product evaluation tasks. The process of answering research questions and mentoring students to be interdisciplinary scholars in a traditional mechanical engineering program influenced how I saw problems and sought to solve them. Mentoring students to become interdisciplinary scholars within a traditional mechanical engineering program changed how I approached problems and sought solutions. So, when classically trained engineers invited me into the field of cyber-physical human systems, I was ready.

Over the past decade, my research has spanned many topics – from integrating human-centric data into algorithms that predict trust in autonomous systems (Akash *et al.* 2018) to studying brain activation patterns in drone operators learning new tasks, with and without distractions. Each step of the journey reflects the spirit of design science – iterative, interdisciplinary and impact-driven. This journey, both personal and professional, has continually reaffirmed for me the power of design science to transform how we think, collaborate and ultimately shape the world around us.

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Beyond my own work, design science has created change in diverse settings. One study helped a large North American government agency apply design research methods to improve operations (McGowan, Bakula, & Castner 2017) and uncover key stakeholder challenges in digital design (McGowan & Simpson 2025). A third demonstrated how improvements in technology versus preferences are the core driver for new electric vehicle consumers (Forsythe *et al.* 2023). Finally, one scholar addressed inequities in Black maternal health by examining how pregnant women in this demographic accessed and engaged with health information – and by identifying ways to improve that process (Burleson, Naseem, & Toyama 2020).

These examples illuminate how design science transcends disciplinary boundaries by addressing practical problems through rigorously theorized interventions. While rooted in diverse domains, what unifies them is a commitment to generating knowledge that not only explains the world but actively shapes it. This dual orientation – toward both understanding and impact – defines the unique value of design science and underscores its growing relevance in today's complex sociotechnical landscape.

Carolyn Seepersad

A defining challenge for design science is developing a deeper understanding of the role of the human designer in the age of machine learning and artificial intelligence. The engineering design community has embraced computational methods for decades, but in the past few years, machine learning-based computational approaches have become so prevalent that they are featured prominently in the majority of papers published in some of our journals, reaching new corners of our research domain and creating new research challenges for the community to address.

Machine learning is permeating a broad range of mechanical design research at a rapid pace. In the first 6 months of 2025, for example, a majority of the full-length research papers published in the Journal of Mechanical Design featured machine learning techniques prominently. One might expect the majority of papers in design automation to feature machine learning applications, given the historic focus of this subfield on computational methods. In fact, many of the techniques classified as machine learning today – such as Gaussian process regression, Bayesian optimization, support vector machines and many others – have been utilized for decades in design automation research prior to being labeled "machine learning." These types of techniques are forming the foundation for increasingly powerful design exploration and optimization engines and are being supplemented by a variety of reinforcement learning algorithms, data fusion methods, generative design frameworks and investigations of human–AI collaboration. It is a bit more surprising, however, to find that half of the papers published in the subfield of design theory and methodology also featured machine learning as a central component in their research approaches. Researchers in design theory and methodology are increasingly utilizing large language models, for example, for several aspects of human-centered design, along with techniques such as latent Dirichlet allocation for identifying patterns and themes in large bodies of text, and generative design frameworks for accelerating conceptual and preliminary design.

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This rapid acceleration of machine learning applications in engineering design is opening exciting new research directions that span the design process – from data mining for identifying trends in customer needs and requirements to augmented reality for designing for manufacturing and assembly – but it raises the question of the role of the human designer in this rapidly changing landscape. To be fair, design researchers are already using these frameworks to work with human designers and customers to learn their preferences, learn their search strategies and augment and channel their creativity and design exploration tasks. As an engineering design community, however, we need to continue to transition from using these machine learning tools to automate portions of the design process to using them to augment the design process in ways that amplify human designers. It will require us to investigate profound questions about the inherent strengths and capabilities of human designers, how they can best work symbiotically with machine learning capabilities, how the machine learning-enhanced design frameworks can best be embodied to interact with human designers, and how the community can leverage these advances to democratize the design process and reshape and rethink the future of design.

Colleen Seifert

DESIGN SCIENCE: Why we need it, what it is and how we conduct it

I can still recall with awe the design process displayed by Allen Samuels, a professional industrial designer and professor of Art & Design (Figure 2). Over the course of a year-long project, he generated hundreds of ideas for a universal-access home bathroom. Working on paper scrolls, he sketched and labeled his flow of ideas in sequence within each design session. His created designs were imaginative, flexible and innovative in considering human needs. Where did these incredible ideas come from?

As a cognitive scientist, I study how people think, how computers might think and how to help learners think about new ideas. But just a few moments with Allen opened an entirely new perspective on the capabilities of the human

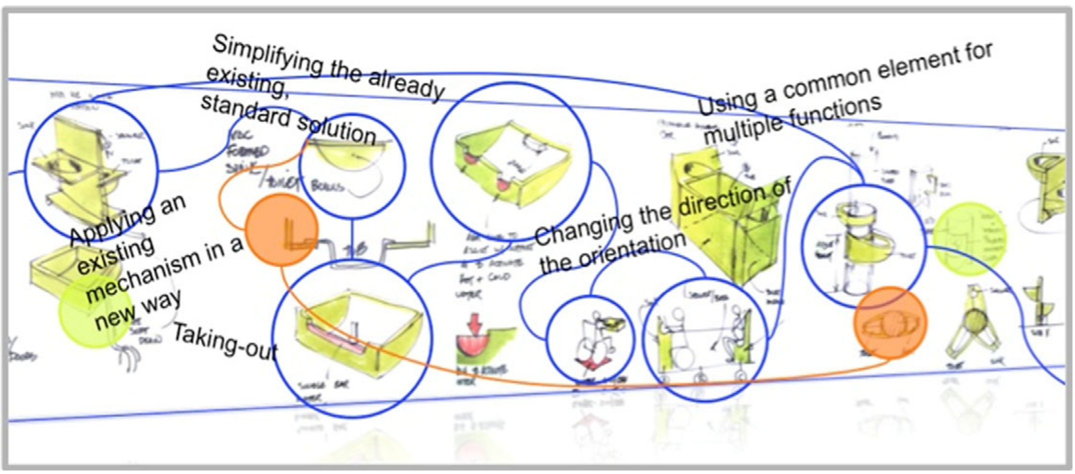

Figure 2. Credit: Allen Samuels, Industrial Designer.

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mind. Cross (1982) described *Designerly ways of knowing* as a method of thinking. At the time, approaches to Artificial Intelligence and rational thought defined only closed problems leading to a single, correct solution (Simon 1969). Yet even without a clearly defined search space, designers create solutions that are surprising, novel and delightful. How?

Design science fills this void in our understanding through scientific (i.e., systematic, reliable) investigation (Cross 2001). How design thinking can generate *unexpected*, previously unknown solutions. The human mind automatically brings past experience and knowledge to bear on a new problem, but this leads to fixation, or perseverance within one viewpoint (Jansson & Smith 1991; Daly *et al.* 2012; Leahy *et al.* 2020). How do designers introduce *intentional variation* to produce multiple, diverse solutions to open-ended problems?

To pursue the origin of design ideas, my colleagues and I conducted many empirical studies of designers in the act of design creation. We collected observations of design sessions, including over 3500 industrial and engineering design ideas for varied problems in the laboratory and in the field. We included students, practitioners and award-winning designers in these studies. Our results documented systematic patterns of intentional variation evident across designs, called *Design Heuristics* (Yilmaz *et al.* 2016).

For example, within his design scrolls, Samuels at times created a new idea that *repeated* the same object form, producing a novel design where sink, shower and toilet shared the same curved arc form. Exactly *which form* is highlighted can be different with each use of the *repeat* heuristic. With training and experience, designers readily learn to apply design heuristics to add variation to their set of candidate design ideas. A total of 77 distinct *Design Heuristics* were identified through empirical studies of designers at work (Daly *et al.* 2012).

Many design scientists continue to contribute important evidence illuminating the magic behind "designerly ways of knowing." Through scientific studies, the field of *Design Science* provides a glimpse into how design thinking moves beyond what exists in the world.

Tripp Shealy

Last summer, extreme heat caused the Third Avenue Bridge in New York City to expand so much that it became temporarily inoperable (NBC 2024). When engineers designed this bridge in 1898, they likely never anticipated the intensity of today's heat waves. This failure points to a broader challenge: we live in the hottest climate in 100,000 years, yet we continue designing using tools, codes and assumptions rooted in historical data. Design research matters because it helps us question these long-held assumptions, see existing systems in new ways, and reconsider the frameworks that shape how we design for an uncertain future.

Consider artificial intelligence (AI), one of the most significant forces reshaping design today. The projected growth of AI-related energy usage in the United States could more than double in the next 3 years due to expanding data centers (Shehabi, Smith, & Sartor 2024). Meeting this demand with renewable energy would require building the equivalent of the largest solar farm in the United States every single day for more than a year. Yet energy conversations tend to focus overwhelmingly on scaling this supply rather than reducing base energy demand.

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While scaling supply is necessary, it is fundamentally a technical problem. Reducing base energy demand requires understanding human behavior and systems. Design researchers, working at the intersections of disciplines that focus on human behavior and cognition, such as psychology, sociology and behavioral economics, are well-positioned to bridge these areas with technical fields like engineering. The value in design research is inhabiting this liminal space that connects the technical with the human, the engineered with the experiential and theory with practice.

Progress toward design that advances society requires overcoming our cognitive limitations. While AI is creating new energy challenges, it also presents a new tool set. For instance, AI can help us overcome present bias, which is our tendency to prioritize immediate concerns over future consequences. Translating mental representations of the future into compelling visual experiences to help designers better connect with future events required an entire PhD dissertation not too long ago (Trump 2024). AI tools now rapidly generate, adapt and evolve future narratives into visual representations. Design research can move further, faster with the help of AI tools. This acceleration opens new possibilities for triangulating findings, generating insights and iterating on research questions at unprecedented speed.

As generative AI moves designers from idea generators to critics and evaluators, we face uncertainty about where this transformation leads. History shows humans adapt to each wave of technological advancement. AI tools hold promises to reduce cognitive load, extend working memory and augment bounded rationality as long as we resist the temptation to treat AI as a black box and instead remain critically engaged with its outputs. Design research must lead in developing new methodologies to assess the quality, diversity and originality of AI-augmented outputs, and in establishing pedagogies that critically engage designers in this emerging hybrid landscape.

Facing unprecedented global challenges, like climate change and AI's societal implications, design research is uniquely positioned at disciplinary intersections and committed to human-centered inquiry. We must leverage these traits to address the defining challenges of our time.

Joshua Summers

If Design Science is the collection of knowledge associated with design, including truths, general laws and theories, then Design Research is the mechanisms that develop this knowledge. While design science is the knowledge or the results, design research is the formal, planned inquiry to discover facts to establish, align and explain design phenomena. This research can be classified across various dimensions:

- Basic research is often considered fundamental research with the scientific aim to improve theories or to predict phenomena (Morse 1950). At the other end, applied research uses these accumulated theories, knowledge and methods from basic research for a specific purpose or desired state.
- Qualitative Research focuses on data collection that is semantic and non-measurable (Szajnfarber & Gralla 2017). This research often includes rich descriptions of the context needed to help explain the relationships. Quantitative

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Research focuses on data collection that can be measured, typically numerically. This research often allows for direct comparisons and evaluations.

- Empirical research is focused on gaining knowledge by direct and indirect observation and experience and is situated in the Real World (Le Dain, Blanco, & Summers 2013). This research requires different approaches for validating and verifying the research, compared with simulation research that is focused on gaining knowledge by means of experimentation or simulation with approximated models
- Inquiry-based research is focused on developing an explanation for an observed phenomenon, often formulated through research questions and hypothesis testing. Problem-based research is focused on developing a solution to a need that has been identified. Invention-based research offers new technologies and capabilities that may eventually be used by others to answer questions or to address problems. Often, inquiry-based research might be associated with basic research, and problem-based research with applied research.

This diversity of types of research is clearly found in the field of design science as researchers approach developing new knowledge with different tools and means. For basic research in design science, one might study team behaviors in highly controlled psychological tests. However, these tests might be used to inform team formation, improve team behavior and thus shift the research down the applied spectrum. These tests could be qualitative in that debriefs and interviews are the source material of data. However, these interviews could be coded for thematic frequency, thus shifting the data analysis to quantitative. While the initial tests are essentially models and approximations of team behaviors, larger-scale projects can be tracked to see if the same behaviors are seen, thus shifting from the simulation to empirical research. Finally, the initiation of the research determines the type as being inquiry, problem, or invention-based research. In this example, the research is primarily inquiry as patterns of behaviors are sought for alignment with team performance characteristics. However, problem-based research might be subsumed as a new means to quickly analyze the text, and converting it from semantic to quantitative data is needed. Thus, there is a dynamism to research as goals, methods and interpretations emerge. It is important to recognize the wide spectrum of types of research and their value in expanding design science.

Recognizing and appreciating the differences is important to continually expanding the knowledge and understanding of design science. As individuals, we need to actively self-monitor to ensure that we do not have any chauvinistic attitudes toward different types of design research, as we within the community are collectively adding to the knowledge base. Our community is perhaps uniquely situated at the intersection of these research types, with several scholars and teams employing many different approaches in this scholarship.

Pieter Vermaas

Design Science and its body of knowledge

Science of design, as advanced by *Design Science* over a decade, has customers, which suggests further development: capturing the body of knowledge.

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Design science has its goals. Internal ones include bringing together the knowledge gathered and making it available to designers and researchers. Designers can use that to improve their practices and understanding. Design researchers can learn about the state of the art and explore how to extend the field. Students can be introduced and become the researchers propagating and developing design science in the next decades. External goals include enabling non-design experts to understand what designing is, to give them tools for applying designing in their fields, and possibly also showing them that design science exists and has its place in the academic firmament.

Design science thus has its customers, and one can wonder if it serves these customers well. *Design Science* is for sure serving design researchers, and the same can be said about other journals in the field. How about the other customers? Designers and students need textbooks and visionary monographs, by which they can learn about the knowledge gathered so far, become inspired and choose their topics for future research. Experts in other fields need brief introductions, survey papers and handbooks to scan what is known about designing and making their choices about how to make use of it. Here, I see opportunities for many more contributions by design science.

One of my last contributions to design science was editing a handbook that brings together the body of knowledge gathered about the designing of engineering systems and making it accessible for future design researchers and experts in other fields (Maier, Oehmen, & Vermaas 2022b). My experience has been that much design knowledge is available and that the editing effort is rewarding and appreciated. But design researchers have, on average, difficulty with surveying and summarizing the knowledge about their topic, and feel more comfortable with presenting new empirical research, claiming novel insights and emphasizing their own approaches. Yet, handbook texts are typically summarizing existing work and integrating it relatively independently of the authors' surveying.

Through my current research, I have become a customer of design science. I work on the development of quantum technologies, and this development has led to prototypes of new types of computers and communication channels. Design techniques and methods are quite interesting tools for exploring the future uses and possible societal impact of these technologies. And for making my case, I can use a simple introduction to designing to convince my new colleagues.

Design science is thriving, and I hope that the next decade leads to a series of massive handbooks and handy introductions for making available its body of knowledge.

Sandro Wartzack

Why virtual product development is more important today than ever before

Design sciences form the backbone of technical product development – and thus a central pillar for a sustainable, innovative society. In light of profound ecological, technological and social upheavals, engineering research is currently experiencing a new, far-reaching relevance. It not only contributes significantly to increasing efficiency and ensuring quality but also provides systematic approaches to tackling pressing challenges such as climate change, resource scarcity and digital transformation.

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The complexity of global problems requires a radical rethink in product development. Climate change, the increasing scarcity of natural resources and the transition to a circular economy make it clear that new, expanded design methods are needed that take into account the entire life cycle of a product – from raw material extraction to recycling. Research and development must therefore increasingly focus on principles such as resource conservation, reuse, modularization and reparability.

At the same time, technological developments are opening up new horizons. In particular, the relatively young field of virtual product development has become a key lever for meeting these requirements in recent years. Based on complete, three-dimensional CAD models – as established since around 1990 – it is now possible to assign semantic information to individual component features during the design phase, define tolerances in a targeted manner and integrate structural mechanical analyses directly.

An important milestone in this regard is the concept of Design for X (DfX), which aims to systematically take into account requirements from downstream areas such as manufacturing, assembly, maintenance and recycling early on in the product development phase. Since around 2000, these requirements can be checked automatically using rule-based systems and production rules (see Wartzack, 2001). With the advent of powerful machine learning methods around 2010, it became possible to dynamically extend these originally static rules with real data from simulation, testing and production, thus enabling CAD-based, AI-supported analyses (cf. Sauer *et al.* 2021).

This marked the logical progression from virtual product development to digital product development. This development was further strengthened by the introduction of the digital twin – a concept that allows real product instances to be digitally mapped and their properties analyzed in real time throughout their entire life cycle. This means that DfX-related tasks such as predictive maintenance or service life forecasts can now be reliably implemented (add reference).

At around the same time, model-based systems engineering (MBSE) established itself as another key approach. Especially in complex large-scale projects, MBSE enables systematic, model-based validation of requirements and creates transparency regarding their degree of fulfillment, any deviations, or even forgotten requirements.

But one thing is clear: development is far from complete. On the contrary, the further development of virtual and digital product development is rapidly gaining momentum. Despite numerous available methods and algorithms, we are still in the early stages of integrating and using artificial intelligence (AI). The potential is enormous, as the following example shows:

Modern, cloud-based CAD systems no longer store their models locally, but centrally in the cloud infrastructures of the providers. This creates a database of millions of CAD models – often carefully designed and compliant with regulations – that are ideal for training AI-based systems. We know what enormous progress has been made in the field of generative AI thanks to large text and image datasets. So why should we not assume that large “CAD models” will soon be able to generate realistic, functional and innovative product designs based on given requirements?

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My personal prediction: In the not-too-distant future, we will be designing with the support of AI in combination with such CAD model foundation models – in real time, interactively and automatically.

And one final appeal: let us not leave the shaping of this future solely to CAD system manufacturers. It is the task of us researchers – especially within the Design Society – to actively help shape this future. Only in this way can we ensure that technological developments also meet our scientific and social requirements.

Maria Yang

What is design science?

Design has been a central human endeavor for millennia, whether driven by necessity or by the natural human impulse to explore and create. Design Science can be thought of as the formal study of the processes and tools used in design, the artifacts that emerge from designing and the range of humans who hold a stake in the design, such as end users and designers (Cross 1999). As implied by the name, it is a field that seeks to uncover design theories and principles and develop models for design.

Why do we need design science?

Design science generates fundamental understanding of the act of designing that can enable new and better products and systems. This is particularly important in the face of the growing sociotechnical complexity of the world we live in today. First, design science can help us understand how to more effectively frame and re-frame problems in ways that can give rise to new perspectives and ways of understanding the true drivers and needs that should be addressed. Second, design science can help unlock the generative aspects of design. Design is inherently synthetic and focused on creativity, idea generation and "making things real" rather than only on analysis (which is, of course, an essential tool). A design undergraduate I know decided to get a graduate degree in a field far different than design. She relayed to me how the detailed analysis and dissection of ideas in this particular field were thrilling, but she missed the generative process of designing. In fact, she told me that her graduate student classmates would always want to be on project teams with her because of her ability to reframe problems and come up with new ideas that were not obvious.

How we conduct design science

Design does not fit neatly in one field but rather cuts across them. Design lives in many disciplines, from architecture, engineering design, product design, interaction design and so forth, which means that design science similarly draws on multiple, interdisciplinary research approaches. One assumption is that how we design is linked to the outcome of design – that is, better design process or more effective design tools correlate with better design outcomes. In my own work, I think about understanding how designers design so we can help them design better. This extends to the tools, methodologies and representations that they use.

And at this moment in time, as in many other fields, Artificial Intelligence (AI) is radically upending the way design can happen. AI is rapidly growing in its capability for generating design concepts with breathtaking speed and with

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increasing representational fidelity (Regenwetter, Nobari, & Ahmed 2022). In response, human designers are changing the way they frame design problems and constraints when working with computational design tools (Saadi & Yang 2023). AI raises new classes of questions about what the process of designing and the role of designers will be like in the not-so-distant future, and will likely open the door to wholly new approaches for conducting design science.

Bernard Yannou

I would like to mention two advances in design in the broad sense that have been made over the past decade, which concern usage-driven innovation and the sustainability of systems and organizations.

Why should we evolve usage-driven innovation methodologies in companies?

The innovation strategy of "Need Seekers" (as opposed to that of "Technology Drivers" and "Market Readers" in Jaruzelski, Staack, & Goehle (2014), which is based on a deep understanding of end-users, although difficult to implement, offers the greatest potential for long-term performance. The Design Thinking approach fails to implement this innovation strategy. It does not sufficiently explore the needs and activities of end-users to provide targeted user categories with useful value propositions – comprising products, services and organizations – that are superior to existing competitor solutions, while ensuring that their development and launch are in synergy with the company's strategic directions. More commercial and business considerations are needed (Cantamessa & Montagna 2016). In the data age, data analysis should also be used to properly frame the problem. Indicators should be available to geolocate value hotspots to be developed by cross-referencing users, needs and relevant activity episodes with regard to the inefficiencies or strengths of existing solutions in the market. Decision-making tools should help design teams make informed choices in order to, at last, enable traceability of innovation processes, which would strengthen confidence in the final solution and allow the project's progress to be capitalized on.

What and how with the RID methodology?

The author developed the Radical Innovation Design (RID) methodology for managing usage-driven innovation projects (Yannou & Cluzel 2024). An in-depth definition of the problem is carried out using ethnographic approaches in order to parameterize and fill in a "cognitive model" of the activity to be revisited. This cognitive model cross-references user categories, usage situations and problems/expectations in order to calculate the quantities of pain that can be reduced or eliminated by using existing solutions. This model is questioned in order to first reduce the sub-market of interest and then highlight the value buckets that are useful to address for users and relevant to the company's commercial orientations. Seven innovative methods are then proposed, adapted to the model-based and data-driven approach of the RID design platform: RID-observe, RID-learn, RID-comparator, RID-compass, RID-creativity, UNPC-monitor, BMC-RID. At the end of the RID process, a final evaluation of the innovative solution is carried out in relation to existing solutions to ensure that there are sufficient margins of differentiation. Ultimately, the RID process (Figure 3) consists of optimizing the pair

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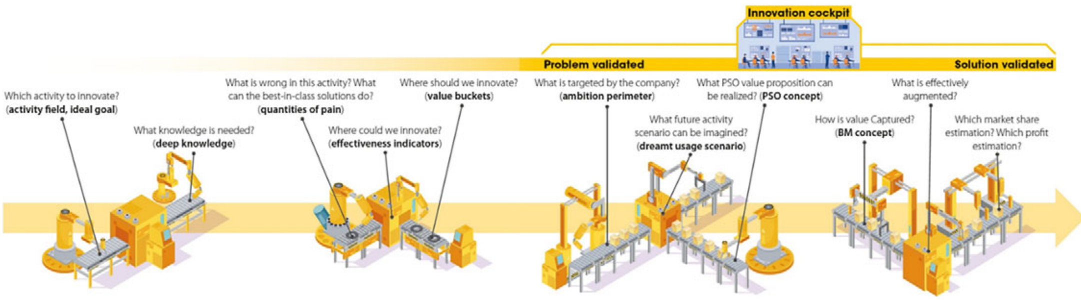

Figure 3. The Radical Innovation Design process is a model-based, systematic and informed process where a clear question is asked and answered at each stage. Some original RID constructs are noted in bold.

(problem, solution) in relation to two performance criteria: usefulness for users and profitability for the company.

My second focus was on the absolute necessity of designing artifacts that guarantee the sustainability of systems and organizations.

Why do we need to develop LCA-based AESA methods?

Conventional LCA methods are relative and comparative, informing improvements in eco-efficiency between options (e.g., diesel versus electric vehicles), but they fail to indicate whether any solution is sustainable in ***absolute*** terms. As global environmental degradation continues despite product-level improvements, the need to respect Earth's biophysical limits – outlined by the nine Planetary Boundaries (PBs) – becomes urgent. Current LCA practice does not ensure that total impacts stay within safe thresholds. Hence, we must develop LCA-based Absolute Environmental Sustainability Assessment (AESA) methods that integrate carrying capacities, ensuring that anthropogenic systems align with ecological limits and do not contribute to system-level transgressions.

What do these methods consist in?

LCA-based AESA methods combine life cycle assessment with absolute sustainability criteria (Bjorn *et al.* 2020). They quantify the environmental impact of a system across categories (e.g., climate change, freshwater use), then compare it to a share of global or regional carrying capacity – that is, the "safe operating space." Estimating these capacities may rely on planetary boundary science or empirical thresholds. Assigning a system its share of capacity involves normative "sharing principles," such as equal per capita, capability to reduce, or economic value added. This comparison yields an Absolute Sustainability Ratio (ASR), indicating how far a system is from its sustainability target.

How? Implementation challenges, political issues and the designers' responsibility

Though theoretically sound, operationalizing AESA is complex. Difficulties include aligning impact categories between PBs and LCA (Kara & Hauschild 2024), choosing fair sharing principles, handling uncertainties in thresholds and resolving inconsistencies in spatial scales. Politically, there is resistance due to potential constraints on growth and trade-offs with competitiveness. Moreover,

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commitments to absolute targets often lack sincerity, particularly where AESA results suggest deep structural changes or reductions in consumption. As such, AESA methods expose not only environmental limits but also the societal and institutional reluctance to fully engage with those limits. Designers who will need to master these approaches will also have to raise these organizational and stakeholder engagement issues and will also have to take responsibility.

Conclusion

As mentioned in the introduction, we invite our readers to reach their own conclusions from the thoughts offered above. Perhaps an AI tool can do this for us, but it may miss the emotion behind these words. We are grateful to the entire design community for their dedication, faith, scientific work, quality of thinking and commitment. We wish that design wisdom will prevail as we continue to design and change the world around us.

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