Perspectives on design creativity and innovation research

10 years later

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1. Introduction (Gaetano Cascini, Yukari Nagai, Georgi V. Georgiev, and Jader Zelaya)

Ten years have passed since the preparation of the inaugural issue of the *International Journal of Design Creativity and Innovation* (IJDCI). The editors at that time collected the reflections and inspiring thoughts of 36 editorial board members in an extended editorial that still represents an insightful overview of the design creativity and innovation research perspectives (Editorial board of IJDCI, 2013).

The launch of the tenth volume of this journal presented an important opportunity to reflect on what has been done and, more importantly, on what is expected of the field of design creativity and innovation research in the years ahead. For this reason, we invited all current members of the Editorial and Steering Advisory Boards of IJDCI to share their expert point of view and expectations in a free style or format (but within a maximum length of words). To guide the writing of their contributions, we put forward the following questions:

- What are the key achievements of design creativity research in the past 10 years? And what is their expected impact on industry and society?
- What are the most promising emerging topics in this research field?
- What will drive design creativity research in the next 10 years? And what will be the priority?
- What research initiatives would you recommend? And what could/should be achieved within the next decade?

As a result of our invitation, 22 board members prepared and submitted short essays addressing one or more of the questions from quite complementary points of view. In order to compare and understand what has changed, we analyzed the contributions for Volume 1 as well as the contributions published in this editorial of Volume 10 along the following three dimensions:

- Research aim,
- Research focus, and

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- The disciplines involved

The first dimension is meant to distinguish between contributions mostly aiming to develop *theories and models*, to influence *practice and application*, or to improve *education* of design creativity and innovation.

The second dimension classifies the contributions according to the primary focus they emphasize. In this case, we recognized three main clusters: those mostly addressing *design cognition*, those emphasizing *design activities and processes*, and those centered around the *outcomes* of design creativity and innovation.

The third dimension aims to distinguish contributions mainly focusing on either *discipline-specific* research or *inter-/trans-/multi-disciplinary* research.

While it is apparent that many contributions address, simultaneously, more than one category of 'research aim' and/or 'research focus' of design creativity, we chose to assign a single code to each contribution based on our interpretation of its central message. This approach allowed us to make a more explicit comparison between the extended editorial of Volume 1 and Volume 10. Two rounds of assessment were conducted. In the first round, we performed the coding independently. In the second round, we compared our classification results and whenever a noticeable discrepancy was found, we discussed until a consensus was reached.

Figure 1 shows the results, and they suggest that:

(1) There is a consistent pattern of how the contributions are distributed across the dimensions of research aim and research focus (indicated by the dotted lines).
(2) A considerable shift emerged from a major emphasis on theory and models of cognition (37% in Volume 1) to practice and application of processes of design creativity and innovation (38% in Volume 10). More broadly, this is also confirmed by the overall transition from theory to practice (most contributions (60%) emphasized theory in Volume 1, but practice (57%) in Volume 10) as well as from cognition to processes (40% of the contributions emphasized cognition in Volume 1, but now 62% of the contributions seem to emphasize processes in Volume 10).

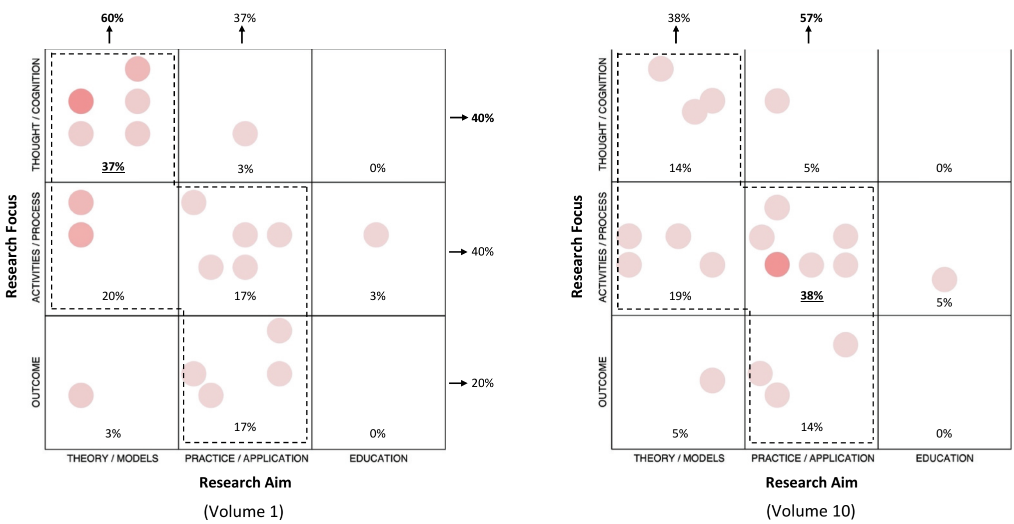

Figure 1. Scatterplot matrices depicting the dimensions of DCI research emphasized by the contributions of the extended editorial of Volume 1 and Volume 10. Note: the color intensity of markers (circles) shows the number of data points (cases) in each bin.

(3) In both volumes, the contributions gave proportionally little emphasis to research on the topic of outcome and to research aimed at developing the education of design creativity and innovation.

Regarding the third dimension of this analysis (the disciplines involved), the results indicate that:

(4) Virtually all the contributions for the extended editorial of both volumes stressed the importance of a multidisciplinary approach to design creativity and innovation research.

Much can be discussed about the four points summarized above, but, for the sake of brevity, we can simply conclude the following.

Overall, the comparison of the orientation expressed by the IJDCI editorial board members in both volumes evokes a simple but important reflection: *the multidisciplinary research in the field of design creativity and innovation must adjust its aims and scope so as to ensure the ecological validity and applicability of its findings and, ultimately, to create a meaningful impact on society.*

The next pages present the authoritative insights offered by the editorial board members who contributed to this extended editorial with the purpose of stimulating reflections and actions by academicians and practitioners interested in this field of study. The contributions are organized according to the three dimensions discussed above.

The next issues of Volume 10 will include further analyses of the manuscripts published in the first decade of the journal and a position paper written by another editorial board member with additional reflections on the inaugural editorial and insights into the evolution of design creativity and innovation research.

2. Design creativity and innovation: theory and models

2.1. Design cognition

2.1.1. Perspectives on design creativity and innovation research – 10 years later (Laura Hay)

As highlighted by Gabriella Goldschmidt in the inaugural editorial for this journal (Editorial board of IJDCI, 2013, p. 7), we have firmly 'left behind the notion that creative design is "magic" that cannot be fathomed'. In the 10 years that have passed since the journal was established, we have greatly expanded our understanding of the cognitive processes underpinning design creativity. New methods have been imported from other fields, and there have been increasing attempts to connect with psychological theory to integrate and build upon the findings of earlier exploratory protocol analyses (Hay et al., 2020). Perhaps most notably, the past decade has seen the arrival of neuroimaging methods in design creativity research, giving rise to 'design neurocognition' as a distinct focus (Gero & Milovanovic, 2020).

Neuroimaging methods (including EEG, fMRI, and fNIRS) have enabled us to measure the brain activity of designers, and begin to piece together the neurophysiological and neuropsychological basis of design creativity. In addition to advancing our scientific understanding, neurocognition research has opened up possibilities for a new generation of methods and tools to support creative design based around emerging neurotechnologies. In the long term, these kinds of tools could even lead to completely new ways of designing not imaginable from our current vantage point. Over the next decade, neurocognition approaches will bring a wealth of new opportunities, questions, and challenges for design creativity research to tackle. Most prominently, there are three areas likely to be of particular importance.

2.1.1.1. Addressing the tension between empirical control and ecological validity in neuroimaging studies of design creativity. Design creativity is a subjective, contextual, and social phenomenon that cannot be comprehensively understood from within the confines of an MRI scanner. Current neuroimaging techniques involve strict controls on conditions, tasks, and behavior that are not conducive to measuring designers' brain activity 'in the wild'. Novel study designs will be needed to produce ecologically valid knowledge about the brain activity involved in creative design, drawing on cognitive neuroscience expertise through interdisciplinary exchange. More fundamentally, advancements are needed in neuroimaging techniques – how can design creativity research contribute to driving these forward?

2.1.1.2. Connecting neural activity with design cognition to develop integrated neurocognitive models of design creativity. Numerous studies in the past 10 years have demonstrated that designers' brain activity during creative tasks can be measured and described using neuroimaging methods. To move forward, we now need to critically reflect on how we can apply these methods to connect neural activity with cognitive processing and explain the neurocognitive mechanisms involved in design creativity. This requires a shift in mind-set from exploration to theory-building (Cash, 2020), and – as above – interdisciplinary exchange with cognitive neuroscience.

2.1.1.3. Translating neurocognition research into impacts on creative design practice. At this nascent stage, it is not clear what kinds of neurocognition questions are relevant to practitioners, or how neuropsychological theory about creative design could potentially be translated into methods, tools, and other applications to support designers. Routes to impact must be identified in the coming years to ensure that research in this area can meaningfully contribute to improving creative design practice. Parallel advancements will also be needed in other areas to realize impacts, including artificial intelligence (AI) and human-computer interaction (HCI). There is a long history of collaboration between these areas – how can these interconnections be developed even further to realize significant impacts on design creativity over the next decade?

From this neurocognitive perspective on design creativity, the key priorities over the next decade are two-fold: (1) understanding *the connection between the mind and brain in design creativity*, as it unfolds in the wild; and (2) exploring how this knowledge can be applied in conjunction with developments in neurotechnology, AI, and HCI to *enhance and expand the creative capacity of designers in practice*.

2.1.2. Perspectives on design creativity and innovation research – 10 years later (John Gero)

In the decade since the start of the journal, we have seen a noticeable increase in interest in researching creativity both within the design domain and outside it. This has been motivated by an understanding of the foundational role that creativity plays within domains and in society generally and by the development of new methods and tools to investigate creativity. In a recent survey by IBM of more than 1,500 chief executive officers, creativity was ranked as the number one factor for future business success – above management discipline, integrity, and even vision. Whilst many design researchers conflate design with creativity, creativity is a research field of its own. Psychologists have had a longstanding interest in creativity, which has become the primary focus of a number of psychology researchers. The American Psychological Association hosts the Society for the Psychology of Esthetics, Creativity and the Arts. Cognitive science has developed a focus on creativity, as has computer science. There is now a continuing conference series Conference on Computational Creativity. New brain scanning tools have introduced novel measurements of creativity. This has resulted in a new organization specifically focused on creativity research based on brain studies: the Society for the Neuroscience of Creativity. Schumpeter in his 1942 book Capitalism, Socialism and Democracy introduced the idea he labeled 'creative destruction', which brought creativity in the realm of economics. All of these activities have expanded the knowledge base on creativity and have provided design creativity researchers not only with new knowledge on which to base their research but also new tools to discover new knowledge.

Design creativity has been the subject of research in the design community that has transcended research in these other communities. By focusing on design rather than a single task, such as the commonly used Alternative Uses Task or the Remote Association Task, design researchers have been able to study creativity in a more ecologically valid manner than is generally seen in psychology, cognitive science, computer science or neuroscience. It would assist design creativity research to engage researchers in these other fields to work on design as the vehicle for their research. This would benefit design by bringing new skills and techniques into design creativity research. It would also benefit those other fields that research creativity by using design as an ecologically valid, non-reducible task that invokes creativity.

Most design creativity research uses single measurement approaches. It is time to use multimodal measurements that include measuring behavior, cognition, physiology, and neurophysiology concurrently. This would allow multiple triangulations of measurements and would improve their reliability. The field should move away from only studying design students (because they are readily available as experiment participants) and study professionals in both controlled and natural experiments.

Finally, the study of design creativity needs to move from only examining design creativity to understand it, to include researching how to improve the outcomes produced by designers by applying the knowledge generated by design creativity research. The next decade of design creativity research promises to be even more exciting as new discoveries about the brain and design creativity open novel areas of potential intervention that improve the creativity of designers.

2.1.3. Creativity as a 'living thing' (Milene Gonçalves)

The first sentence of the inaugural issue of this journal stated that design, creativity and innovation are 'living things moving in a field' (Editorial board of IJDCI, 2013). It brilliantly paints a picture on how researchers, in an attempt to understand the vibrant phenomenon of creating, tend to dissect this living thing until it is not moving anymore. More importantly, it extends on the dichotomy that most researchers on creativity and innovation struggle with: to accurately describe creativity we might staunch it or lose track of its essence; on the other hand, to investigate creativity 'as it moves in the field', we might lose objectivity (or even lose ourselves in the movement).

Fast forwarding 10 years, and how are we coping with this challenge? How much has the world changed and forced us to keep critical and adaptable? There is a widespread clamor for creative thinking and flexibility, especially in the hiring process of the new workforce (Adobe Research – Distance Learning for Higher Education: Get Hired, 2019; World Economic Forum, 2020), but are we researchers keeping up with the times?

I see most of our attempts falling on the first category: we tend to sacrifice the 'living' nature of creativity for the sake of robustness and repeatability. But are there ways that we can achieve the best of both worlds? More specifically, can we scientifically study design creativity as it 'moves in the field', using dynamic approaches?

Situated creativity is not a novel topic, albeit not extensively explored. For instance, Perisic et al. (2019) demonstrated the need for novelty to be assessed as a situated measure, as what is considered 'new' tends to change, even while designing. However, the underlying assumption of most research studies, especially in those focused on the evaluation and definition of creativity, is that this is a fixed construct. But how can that be? Novelty (together with usefulness, the most widely agreed-upon components of creativity) by itself demands that time is considered – is the idea new and useful *now*, considering what has been done in the *past*?

As Barbara Tversky exposed, in her views on creative thought (Editorial board of IJDCI, 2013), creativity is 'content-bound': with the change of the situation, the object being studied changes as well. I join then my voice to those who study creativity as a situated phenomenon, where dynamic approaches can be adopted.

As creativity changes over time, we too should explore robust and reliable tools to capture the living nature of creativity, as it changes. There are multiple approaches to explore:

- Judging creativity: rather than measuring it as a fixed construct, researchers should acknowledge the changing nature of creativity. We should develop more nuanced and situated 'estimations' of creativity (Corazza, 2016).
- Considering creative thought, action and outcome: As elusive as it is, creativity can be manifested in many ways. An integrative way to examine creativity, combining creativity cognition, behavior and outcomes, could provide not only a more complete understanding of the phenomenon being studied, as well as offer finer perspectives of the situation (Gonçalves & Cash, 2021).
- Considering time in the analysis of creativity: A number of more dynamic approaches to study creativity has been proposed by Beghetto and Karwowski (2019). Such approaches could include latent growth modeling and network-based analysis, where multiple measures of creativity are taken over time.

These are just a few possibilities available to us to explore the fluidity and fleeting nature of creativity. As we experience ever-changing situations, with the boundaries of design expanding and blurring, it is crucial to acknowledge that even when researching and teaching creativity, we need to be flexible and adaptable. After all, as researchers, we are also creating.

2.2. Design process and activities

2.2.1. Design creativity as part of general creativity: a call for enhanced interdisciplinarity (Nathan Crilly)

A recent research manifesto published in The Journal of Creative Behavior emphasized the way in which creativity displays both similarities and differences across situations and across domains (Glaveanu et al., 2020). Considering the last decade and more of design creativity research indicates the need to think much more thoroughly about what is specific about design creativity and what is general to creativity more broadly. Doing so would require design creativity research to engage more critically with the interdisciplinarity that is often said to characterize the field. Here, I argue for this rather general form of development with particular reference to two of the most important topics in design creativity research: co-evolution and fixation (see analysis in Christensen & Ball, 2019).

'Problem-solution co-evolution' describes how designers' representations of problems and solutions develop in parallel, each influencing the other. This is a topic that has sometimes been presented as though it is a unique characteristic of design, distinguishing design from other activities. However, other disciplines have described similar phenomena in a wide range of creative practices, including visual art, writing, music composition, entrepreneurship, policy formulation, mathematics and science (see review in Crilly, 2021). Research into design co-evolution has been conducted entirely independently of these other accounts, even though connecting with them would provide valuable insights into how co-evolution relates to activities that design researchers are concerned with, such as education, collaboration and negotiation. What's more, thirty years of research into design co-evolution has much to offer creativity research more generally, where processes of problem finding and problem solving are studied, but primarily as separate and sequential activities (for a recent review, see, Abdulla et al., 2020). By presenting design co-evolution as the reciprocal interaction of problem-finding and problem-solving activities, we would be better placed to contribute to more general creativity research efforts.

'Design fixation' can be seen as a form of cognitive bias that is observed in creative work. It is typically described as designers' persistence in repeating familiar structural elements in response to functional requirements. For 30 years, this characterization of fixation in design has been productively studied and theorized. However, fixation on structure is not the only kind of fixation relevant to design. We can separately identify fixation on function, fixation on process and a wide range of other biases that have been elaborated beyond design research. For example, recent research published in Nature describes the 'addition bias', in which simple design exercises were inefficiently solved by preferentially adding rather than removing components (Adams et al., 2021). In contrast to work in other fields, design creativity research seems curiously biased in emphasizing just one of the many forms of bias that are exhibited in design. It would be helpful to have a thorough multi-disciplinary review of biases relevant to design work, identifying findings that can inform how we think about, study and seek to influence design. This could also identify places in which current knowledge is unsuitable for transferring to design activities and so where further design-specific research is required. This further work could usefully be published not just in design research venues, but also back to the other communities that study relevant phenomena and practices, but seldom in the context of the open-ended tasks that design researchers focus on.

Of course, the issue of interdisciplinarity relates not just to these two topics, but also to other theories and processes relevant to design creativity research. Adopting a more interdisciplinary approach would also connect design research to work in which the same topics are being studied by other methods (including longitudinal studies and life histories), where creativity is specified in other ways (because of different paradigms and perspectives), and where a continuous relationship to older studies is maintained (both through the literature on creativity and other subjects). These are all issues emphasized in the manifesto by Glaveanu and colleagues, and so we would not be alone in striving to address them. Instead, we would be engaging in the same project as creativity research more generally. What better way to forge stronger connections?

2.2.2. Perspectives on design creativity and innovation research – 10 years later (Ricardo Sosa)

The last decade has registered an expansion of the field of design research as evidenced by the growing number of journals, conferences, and graduate programs around the world. This growth in researchers and outputs goes beyond quantitative aspects, and has made the area more vibrant, more diverse, and more inclusive of diverse epistemological and methodological approaches. The International Journal of Design Creativity and Innovation has delivered on its promise to welcome a variety of approaches to the study and support of design creativity and design innovation. This journal has helped disseminate and inform research that is markedly different from those targeting creativity or innovation from other disciplinary angles. A review of its most read papers shows a diversity of theoretical concepts and research questions, an inclusiveness of multiple methodologies, and a tendency toward applicability in practice. Research in this area crosses disciplinary boundaries and IJDCI has gained a reputation for high-quality work that would otherwise be published in the academic silos of yore. That is the main achievement of design creativity research in the last decade: supporting a conviviality of voices and approaches that inform and inspire the work of a growing and diverse community.

The main challenges in this area can be organized in three groups: conceptual clarity, quality assurance, and cross-pollination. By conceptual clarity, I mean that researchers in the field are likely to increase their emphasis on the foundational ideas of their work beyond the conventions and accepted assumptions of the past. Namely, since 'ideas' are the elementary particle of much of our work, it is relevant to ask: What is an idea? Whether we study design ideas using fMRI equipment, think aloud protocols, algorithms, statistical models, or ethnographic coding, the field needs more clarity within and between these types of studies when it comes to defining what counts as an idea in design. More explicit and sound principles will help evaluate and compare contributions to understand the processes of design ideation, build systems to support designers, and inform ways to educate future designers. This 'back to basics' is not a sign of an immature field, quite the opposite: marked progress has been made in other fields when researchers formed in different traditions make a joint effort to define deceivingly simple but foundational concepts such as genes, species, and gender. By quality assurance, I believe that we will continue to see journals and conferences in this area placing increasingly stringent quality criteria and methodological clarity in their review processes. Far from this leading to the dryness and narrowness of more traditional fields, I believe that communication across disciplinary lines tends to move us toward better practices as we adopt and adapt our methods of inquiry and formulate our contributions to theory and practice. Lastly, by cross-pollination I hope that more researchers in the area will further inform and base their research on studies and work carried out within and outside of their research paradigms.

Personally, I am appreciative for the rising uptake of computational approaches for the study of design creativity and innovation. The use of agent-based social simulations to model emergent phenomena of interest has expanded considerably in the last ten years and has clear potential to inform theory, strategy, and policy in the future. A clear advantage is their suitability to examine multi-level phenomena to study design creativity and innovation in the interaction between individuals, teams, institutions, societies, and culture (Sosa & Gero, 2016).

2.2.3. Fundamental processes of design creativity: New Findings and Trends (Ashok K. Goel)

Creativity in design is characterized by ill-defined design problems and ill-defined evaluation criteria, an iterative design process, and co-evolution of the design problem and the design solution through multiple iterations. The question then becomes what are the cognitive, social and technological processes that lead to iteratively better understanding of the design problem and solution? My colleagues and I have been examining this question since the mid-eighties. Our methodology for studying these processes combines cognitive studies of design, development of information-processing models, construction of computational techniques, and deployment of interactive tools for aiding creative design.

In my section of the 2013 IJDCI editorial, I had identified four fundamental processes of design creativity that we have investigated: systems thinking, analogical thinking, visual thinking, and meta-thinking. Briefly, for systems thinking, we have developed a theory of Structure–Behavior–Function (SBF) modeling that uses function as an abstraction to decompose a system into subsystems and to organize knowledge of the processes and components of a subsystem at a given level of abstraction (Goel et al., 2009). For analogical thinking, we have identified a spectrum of design creativity and developed an integrated theory of model-based within-domain and cross-domain analogies that addresses multiple points on the creativity spectrum (Goel & Bhatta, 2004). For visual thinking, we have developed techniques that use only visual knowledge (Davies et al., 2009), only conceptual knowledge, or multi-modal knowledge and reasoning to enable analogical transfer in creative design (Yaner & Goel, 2008). Finally, for meta-thinking, we have developed a theory of adapting the design process to new tasks, for example, adapting an agent's reasoning for assembling a system into a strategy for disassembling the system (Murdock & Goel, 2008).

Over the last decade, we have continued to investigate the above four reasoning processes, mostly in the context of biologically inspired design (Goel et al., 2015). Here, I briefly summarize four recent findings and trends emerging from this work. First, we have developed an empirically grounded knowledge representation scheme for specifying design problems. The representation scheme called Four Box (Helms & Goel, 2014) enables the specification of the desired function, the operating environment, the structural constraints, and the performance criteria, and adds to the relatively sparse literature on design problem representation. Second, we have identified two distinct roles for analogical thinking in creative design that we call problem-driven analogy and solution-based analogy (Helms et al., 2009). Given a target design problem, problem-based analogy finds a source analogue and transfers relational knowledge from the source to the target. In contrast, in solution-based analogy, a source analogue (for example, in biology) helps identify novel design problems and/or criteria for evaluating design solutions (for example, in engineering). Put together these two findings begin to provide a partial account of defining design problems as well as defining the evaluation criteria for them.

The third finding from our work over the last decade pertains to the use of technology in biologically inspired design practice. In the modern age, designers typically search the internet for source analogues for addressing novel problems, which is often an arduous process (Vattam & Goel, 2011). Finally, the fourth finding refers to the need for interactive AI tools that can help designers locate and understand information on the internet, for example, by extracting SBF models of systems from design drawings (Yaner & Goel, 2008) or text documents (Goel et al., 2020). Put together, these two findings highlight a major trend in research on creative design: use of AI, machine learning, and visual and language processing for locating and understanding large-scale design information available on the internet.

2.2.4. Design theory and creativity: fruitful results and promising frontiers (Pascal Le Masson)

Ten years ago Armand Hatchuel called for stronger interactions between Design Theory and Creativity Research, two long separated scientific fields, (Editorial board of IJDCI, 2013). These interactions were made possible by the strong support of the Design Society and its Special Interest Groups (SIGs), in particular Design Creativity SIG and Design Theory SIG.

Three original streams emerged from these new interactions, each one opening promising topics.

First, in design-theory-based experiments design theory, in particular C-K theory, (Hatchuel & Weil, 2009) helped to formulate new, original hypotheses and to elaborate new measurements protocols to address critical creativity research questions with an experimental approach. It became possible to better diagnose fixations, in individual as well as complex collective situations (Agogué et al., 2014, 2015, 2012; Camarda et al., 2018; Plantec et al., 2019; Rémondeau et al., 2019); based on design theory and creativity, works shed light on defixation processes, opening avenues for creativity education or uncovering the role of defixation leadership (Camarda et al., 2021; Ezzat et al., 2017a; Ezzat et al., 2017b; Ezzat et al., 2020).

Second, advances in design theory enabled to propose enriched models of creative reasoning, shedding light on the impact of knowledge and knowledge structure on generativity. This enabled to address creativity issues in knowledge-intensive situations. Research results have shown how Bauhaus courses actually taught so called ‘splitting’ knowledge to improve designers creativity (Le Masson et al., 2016). This same logic of ‘splitting knowledge’ was then analyzed in very different situations: it appeared critical for the creativity of architectural sketching (Brun et al., 2016); it was also the critical feature in the management of radical innovation projects (Lenfle et al., 2016).

Third design theory rendered possible to analyze creativity processes in situations where generativity was less expected. Design theory was applied to decision theory to analyze systematically how to design decision in the unknown (Le Masson et al., 2019), hence opening new ways to link decision and creative design, that were applied in Public Decision-Making (Pluchinotta et al., 2019). Advances in design theory also helped to analyze innovative design within tradition, revealing generativity processes associated to the creative preservation of tradition in creation heritages (Hatchuel et al., 2019). And more recently, design theory was used to characterize generativity in apparently ‘closed worlds’ (Arrighi et al., 2018), namely generativity associated to so-called generative design algorithms – these analyses revealed that actually generativity could be associated to the creation of object topologies (Hatchuel et al., 2021).

Behind these research results, there are key drivers. Advances require a constant interaction between theory and experiments – advances in design theory have enabled to formulate original hypotheses on until then unconclusive or contradictory situations; design theory has also been required for the development of new analytical instruments, adapted to the systematic observations of new creativity phenomena. And experiments and empirical analyses also led to raise new questions for design theory. This interaction proved fruitful in the past years and will remain a key driver in the future.

One can hope that this strengthened interaction might lead to experiment in a variety of research fields, beyond the one explored today – how could research results be deployed and experimented at greater scale? This might be required in education, where our societies require to train people to be ready to invent creative solutions to face contemporary common threats and transitions. This might also be required in companies, that need to ground innovation organizations and processes on improved models of creative thinking.

New models and instruments for creative reasoning might today help deepen the analysis of generativity in knowledge intensive domains. One example could be the creation of scientific knowledge, where these models might enable to go beyond psychological approach of scientific creativity, to analyze how scientific knowledge structures leverage generativity in scientific disciplines. Another example could be technological invention, where relevance and rigor of creative models of thought today enables to uncover how patent law developed as a management norm of technological invention (Valibhay, 2021), so that researchers wonder how to rely on models of creative thought to develop a patent law adapted to contemporary challenges (Landers, 2010; ValibValibhay et al., 2020).

Developments in the last 10 years led to think that design creativity is not a subfield of psychology or cognition but addresses the universal issue of models of creative thought. IJDCI contributed to this pioneering approach in the last decades and one can hope that it will go on attracting papers exploring this frontier, from its deepest theoretical foundations to its most impactful consequences in our societies.

2.3. Design outcome

2.3.1. Design creativity research: a peek into the past and a glimpse of the future (Srinivasan V)

Research on design creativity broadly answers one or more of the following questions:

(1) What is design creativity? (or) What is a creative design?
(2) How is/can design creativity (be) assessed? (or) How does one know whether a design is creative or not, and to what degree is it creative?
(3) What factors influence design creativity? (or) What factors influence the development of a creative design?
(4) How can design creativity be (better) improved or supported? (or) How can one improve the chances of developing creative outcomes?

These questions are listed in the descending order of fundamentality. In other words, the answer to Question 1 is needed to know what needs to be measured or assessed, before figuring out how it can be measured or assessed. The answers to Questions 1–2 are needed to estimate whether a factor influences design creativity positively, negatively or has no influence. The answers to Questions 1–3 are required to ascertain how and whether design creativity can be improved or supported better.

Much research on design creativity caters to the Questions 3 and 4 with comparatively fewer efforts to answer the more fundamental Questions 1 and 2. These pieces of research adopt the seemingly accepted definitions and measures of design creativity. On the one hand, within the community pursuing research on design creativity, there seems to be a shared understanding of what is design creativity and what it encompasses. For instance, Sarkar and Chakrabarti (2011) define design creativity as the ability of an agent to develop outcomes that are both novel and valuable. Apart from novelty and value, surprise is also considered as a measure of design creativity (Brown, 2012; Maher & Fisher, 2012). But on the other hand, though there has been sizable effort on research into assessment or measurement of design creativity (e.g. Shah et al., 2003; Sarkar & Chakrabarti, 2011, etc.), this research has not reached the stage of convergence where the community can accept the metrics developed without caveats and has been continuously evolving. In other words, several researchers have developed and proposed multiple ways to assess or measure novelty and value and surprise, and all these seem acceptable in the context in which these have been used. However, there is a need for some form of benchmarking to arrive at a common set of metrics to assess or measure design creativity.

With the second coming of Artificial Intelligence (AI), researchers from various disciplines are developing interesting AI-based applications that can perform tasks efficiently and effectively. Design researchers have also leveraged on the AI reemergence, and in design, AI has demonstrated significant potential to augment the human abilities. Research in design creativity offers great scope for assimilating AI and can help with answering Questions 2 and 4. For instance, AI-based applications can help identify, explore and validate solution spaces, help generate and evaluate novel solutions over and above human capabilities, etc.

With the advancement in technology, there is greater impetus than before to understand how the human brain works. This opens up avenues to identify deep insights on design cognition and their implications on design creativity in terms of measures, influences and support. So far, research on design creativity has been based on parameters external to the cognition with little or no effort into identifying or understanding the parameters within the cognition due to lack of sufficient means to investigate. This advancement in technology to better 'read' human brains will allow deeper study and understanding of cognitive processes within the brain than before. Consequently, it will allow undertaking research into internal parameters of cognition relevant to design creativity, and develop insights in terms of metrics, influences and support based on the internal parameters, which are relevant to answer Questions 1–4.

3. Design creativity and innovation: practice and applications

3.1. Design cognition

3.1.1. Perspectives on design creativity and innovation research – 10 years later (Jean-François Boujut)

Who could have imagined 20 years ago that we would send tourists into the space while a young activist of 16 years old were shaking the politicians and put them in front of the inconsistency of their environmental policies? Who could have imagined the reaction of the whole humanity in face of a global pandemic? The creativity of the human being is infinite, being the innovation social or technological, environmentally friendly or desperately resource expensive.

My experience of creativity is that it seldom comes where one is expecting it. So, do we need more design creativity research? Yes indeed. Many progresses have been achieved in the last decades. Among them we can cite Design Thinking as a great achievement as it makes popular a classical approach of design that was limited to few specialists in the past. Today almost every engineer has heard about design thinking and knows at least some of its basic principles. This gave birth to agile methodologies and more lean design approaches. These approaches are no more research topics as they entered in the public domain of the daily practice.

Recently, the reaction of thousands of people who started to create new devices, masks, shields, respirators, ventilators, and all sorts of devices to help the hospital personnel is amazing and was totally unpredictable. Can we say that our research results allowed this emergence of so many private initiatives? This is far to be obvious. However, we can say that the technological breakthrough of the digital and collaborative era of social networks and collaborative platforms helped remote people to stay in contact and work together in a distant mode. A massive distributed, shared, asynchronous creativity strongly emerged and became visible during the pandemic. This is certainly one of the good news of this tragic episode. We demonstrate that the humanity has the collective capacity to react, organize and eventually create things that help us to overcome exceptional situations.

Many research questions arise from this and challenge the traditional models of innovation we have as well as our understanding of creativity as a thought process. What we witnessed during this episode was the emergence of a collective thought process and a distributed and collective production process. Open-source initiatives produced low cost, frugal solutions in a totally unstructured and non-conventional way. Also, design theory made significant progress in the last decades and our understanding of creativity as a cognitive process is now well established. As mentioned before, this gave birth to methods and tools used every day in companies.

What is at stake today is more surprising. Creativity is no more the job of a few well-trained specialists. We must understand as researchers how this massive collective movement can be understood and equipped, how a theory of distributed collective creativity can emerge. This is also true on the companies' side. New societal challenges cannot be addressed from a unique perspective, as for example, the big challenge of the future of mobility, or sustainable production. Entire ecosystems must cooperate, including actors of very diverse nature ranging from public authorities and policy makers to individual citizens and including of course private actors but also associations. This will drastically change the conditions of innovation and therefore raises theoretical and practical questions to the researchers. This is a very exciting future of creativity and innovation that is in front of us.

3.2. Design process and activities

3.2.1. Design creativity research – What, How and Why (Gabriela Goldschmidt)

In the inaugural issue of IJDCI in 2013 (Vol 1, Issue 1) I wrote that the greatest challenge for the design creativity research community is studying design cognition, as this was seen as the optimal way to fathom creative design processes. Looking at processes appeared essential after decades of focus on creative products and creative individuals.

In 2019 in an IJDCI editorial (Vol 7, issue 4), I maintained that the most important developments in design creativity research are novel approaches to studying them, which are Artificial Intelligence and Neurocognitive investigations. These paths allow for much more fine-grained and accurate findings, which are necessary as we recognize the highly complex phenomenon of creativity. This time, more than relating to what to study, the focus was on how to study creative design processes.

Some two and a half years later, what can I add? I think that today we must acknowledge the fact that from a societal point of view we are somewhat less interested in the creativity of individuals and more eager to look at group creativity. In the current economic reality individuals hardly ever work alone: they are always part of a team, a group, a collaboration that endeavors to come up with the most creative outcome to a design concern. Furthermore, more often than not such teams and groups are multi- or interdisciplinary: designers work with other professionals, scientists or entrepreneurs to reach the goal. In fact, there is evidence that mixed teams, representing more than one discipline, usually turn out more creative results than uni-disciplinary teams, including in design (e.g. Aggarwal & Woolley, 2019; Somech & Drach-Zahavy, 2013). We must therefore shift perspectives and learn to study creativity in those settings. We thus turn to the question of why study design creativity, in this case presumably to have more of an impact on the business and industry worlds. Figure 2 summarizes the above claims.

Having an impact in the business world from the designer's point of view should mean creating more value for stakeholders – the end user, the enterprise, and society at large. Today there are several methods, or approaches, employed to that end, notably Design Thinking, Lean, Triz, and more. But we know all too well that their application is not always a success, owing to a host of problems. In general, methods have never been wholeheartedly welcomed by the majority of designers in many design disciplines, as accentuated by the failure of the 'design methods movement' that originated in the UK in the 1960s (Cross, 1993). Therefore, we must find a way to augment AI methods and budding understandings emerging from studies involving neurocognitive

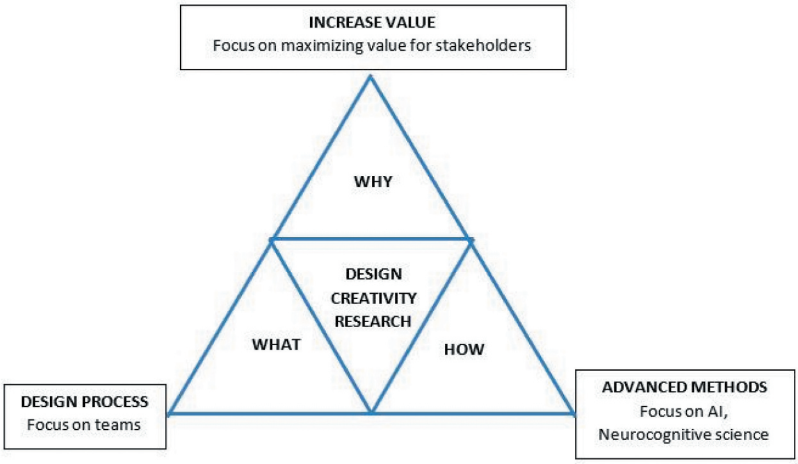

Figure 2. Anticipated why, what and how of design creativity research.

studies of design and designers toward the study of processes by design teams, in order to learn how their creativity may be enhanced. This is a major mission of the design research community for the next few years.

3.2.2. *Creativity research to support engineering design (Elies Dekoninck)*

In the last 10 years, design creativity research has focused on two main approaches: conducting systematic studies to provide evidence for the effectiveness of tools and methods; and some more fundamental research on creative behaviors and creative phenomena that are particularly relevant to designing. Design researchers have investigated a wide range of tools methods and approaches using a variety of different research methods, whilst attempting to adopt best research practise to ensure some rigor and repeatability. There is quite a large time lag between conducting the research and seeing subsequent practise changes in industry and society (probably about 10 years in itself). However, despite this lag, one could argue that – particularly in technical engineering design contexts – this type of research does have a positive effect on practise. By having evidence showing that tools, methods and approaches of creativity improve the efficiency and effectiveness of engineering design activities, teachers and practitioners of engineering design are more likely to be comfortable adopting, teaching and promoting these tools. In other words, due to the increasing availability of evidence from design creativity research, practitioners and teachers can check the likely outcomes of adopting new tools, methods and techniques and are therefore more likely to use them.

As design creativity research has investigated a wide range of creativity tools and practises over the last 10 years, there is a gradual blurring of the boundaries between the softer design thinking approaches to creativity and the more systematic creativity/problem-solving methods. Students and practitioners alike are comfortable trying out tools across this spectrum for their own practise and deploying them with colleagues. A wider variety of different types of tools appear to have been become more accepted in the last 10 years.

In technical engineering research, interest is rapidly growing in AI and big data and how this will influence engineering design practise. This has rolled over into creativity research where researchers are beginning to look at how AI tools will work together with human cognition to support design creativity. This is an interesting topic but tends to be linking one computer with one practitioner. However, future design creativity research needs to keep sight of the knowledge needed to support creativity at the team-, organization-, community-, profession- and company- levels.

In engineering design, there is a great shortage of new engineers coming into the profession at all levels. One strategy to attract more people into the engineering profession is to radically change the perception of engineering education from one which focuses on the accumulation of knowledge, toward a perception where engineering is seen as a process that involves creativity, design and innovation (Fidler, 2021). Secondly, there is a strong understanding in education that we need to be educating and providing experiences whereby people can work across multidisciplinary teams to solve our planet's most urgent and important problems. Design creativity research will need to focus particularly on how the tools methods and techniques are best used in the context where team members from different foundations and stances come together to solve complex and interconnected problems. In this context, design creativity research might for example, investigate how softer design thinking approaches to creativity and the more systematic problem-solving methods can support these multidisciplinary teams. In the next 10 years, design creativity research needs to support the development and testing of tools methods and approaches which build the confidence of a new and diverse cohort of multidisciplinary teams to tackle the complex and interconnected problems that urgently need solving.

3.2.3. Design teams' creativity in a complex ecological system – a key topic of future research (Dorian Marjanović)

For the last few decades, globalization and continually increasing complexity dominated new product development (NPD). The recent year added uncertainty as a key constraint on the design teams already performing simultaneously in multiple companies, disciplines, and domains in highly complex collaborative environments dictated by multiple factors like demographics, technology, or domain diversity. The immanent pressure for continuous innovation vital for the company's competitiveness demands engineers to produce creative solutions to design novel products.

Academic research on creativity has been a vital research topic in social and engineering sciences. Therefore, as fundamental research areas regarding design and NPD, four branches of sciences might be highlighted: psychology, sociology, business, and design (Figure 3).

Such a broadness and diversity of research efforts throughout different disciplines cause usage of domain-dependent vocabulary that does not contribute to the unification of the research area.

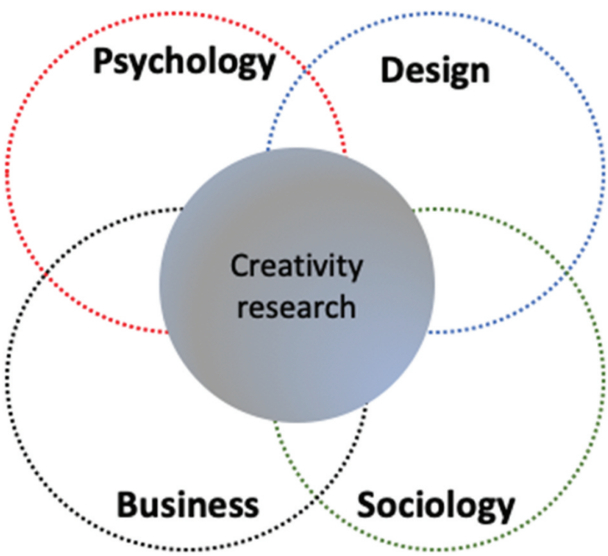

Figure 3. Key disciplines of creativity research.

Research in psychology was traditionally focused on individuals and personal factors of creativity. In contrast, researchers from sociology were focused on the macro perspective, the social and ecological contexts of innovation and creativity (Burns et al., 2015). Organizational factors are the focus of research concerned with business processes and management particularly.

The research in the design area has been dominantly focused on understanding the creativity and innovation of designers (Taura and Nagai, 2017). Therefore, the key research area is generative processes that create ideas and exploratory processes that evaluate them (Lindemann, 2022). In addition, research of individual factors that inhibit/stimulate the creativity of the designers and teams, including methods and computer-based tools that stimulate idea generation, have been extensively reported (Shah et al., 2001), (Han et al., 2018), (Albers et al., 2018) at conferences and journals.

Although a significant part of the research on the topic is focused on the individual, recent research reports consider the role of R&D teams. Research on team creativity is still relatively sparse (Reiter-Palmon et al., 2012), focusing on team composition, participants' cognitive style and personality, and team management. Most of the academic research does not consider the realistic circumstances of NPD performed simultaneously in the multiple companies in a complex ecological system dominated by domain depended technology, standards and rules of operations. Such a diverse influence of technology including emerging AI tools on R&D teams' creativity is omitted as a research parameter in the literature. We believe that the research on team creativity concerning realistic circumstances of NPD should be the cornerstone of future research in this area.

3.2.4. People are creative, companies are innovative (Damien Motte)

By choosing to link explicitly creativity and innovation in its title, the founders of the International Journal of Design Creativity and Innovation made the important point that creative output and its exploitation need to go hand in hand.

The study of creativity is in majority oriented toward individuals and teams, be it for understanding and modeling creativity at a detailed level or for development of tools, the latter of-ten within the scope of a real or fictive design project. Innovation studies have, at the compa-ny level, often focused on enablers, or processes facilitating the creation, harnessing and ex-ploitation of ideas. Cross-pollination has led to fertile results in both research areas. Innova-tion studies have implemented for years results from creativity studies, taking into considera-tion the importance of employee motivation, the formation of suitable development teams, the need for freedom, etc. Vice-versa, new contexts have triggered further understanding of crea-tivity and development of tools. Such integrated research studies have appeared in IJDCI (Crilly, 2018; Taura & Nagai, 2017; Yannou, 2013).

In these last 10 years, new areas have emerged or have been reinvigorated within the combined studies of innovation and creativity. Two of them that might present – at different levels – interesting theoretical and practical implications for the years to come, are presented below.

One area is continuous improvement. The basic principles of continuous improvements are: 1) It is always possible to improve a process or organization; 2) The improvements are mainly bottom-up; 3) The improvement loop is virtuous, the benefits perceived by the employees motivating them to continue improving their activities. This opens several areas of enquiry for research: the implementation of continuous improvement in design activities; its impact on creative and innovative output; the interplay between top-down process and organizational models and bottom-up improvements; the emergence of so-called excellence centers in com-panies (several denominations exist), whose role is to deploy and support continuous im-provement, etc. The concept of continuous improvement might also lead to adapting some research practices: developed methods might be introduced earlier as they are likely to be fur-ther adapted and improved; validation of some methods and process models might be post-poned, if ever undertaken, to after their implementation, as they will be continuously altered.

Another area is employee-driven innovation (EDI). Originally, EDI deals with 'the generation and implementation of new ideas, products, and processes – including the everyday remaking of jobs and organizational practices – originating from interaction of employees, who are not assigned to this task'. (Høyrup, 2012, p. 8). This definition can be extended to designers, with ideas that appear during their work but without possibility to develop them within their current assignments. Such ideas can be very valuable as they are often deeply related to the employee's experience, therefore appropriate and even novel. Few companies can afford to give their employees some 'free' time on a regular basis, hence the suggestion box. But it has been realized that, in practice, the employee is the person who is best suited to further develop the idea. This poses the problems of idea selection, of trust (will the employee be up to the task?), and of effectivity, which is paramount to innovation management. This can have im-portant theoretical implications in the creativity field as well: serendipity, that creativity methods have tried to tame, regains a central place in EDI; EDI might also extend the concept of creativity from individual or team-based, to corporate-based.

3.2.5. Perspectives on design creativity and innovation research – 10 years later (Bernard Yannou)

I usually situate my research on design creativity and consider the research of others under the perspective of useful (re)design of the value offer. Useful means to me that our designing society uses too much raw and nonrenewable materials, produces too many waste and CO2 emissions, without guarantee that new ideas, products, services and systems contribute to happier lives individually and socially (see, Papanek, 1971).

Once said, in the last decade, creativity activity has been better included into the innovation (Cantamessa & Montagna, 2016) and entrepreneurship processes as in the case of lean startup (Reis, 2011). The link between creativity, innovation and entrepreneurship has started to be seriously studied (Luo, 2015) even if some user ethnographic and company managerial considerations are often omitted in the creativity and innovation methods developed by researchers. In addition, after Norman and Verganti (2014), human-centered design (HCD) approaches like design thinking proved to be incremental design, with no incentive to push new meanings and explore new innovation areas but rather incentives to fix some identified pains.

This is the reason why I contributed during the last decade to develop the Radical Innovation Design (RID) innovation methodology. RID is based on a clear reference framework and a solid systemic approach, where the guiding focus for innovating is on the improvement of the activity system (Engeström et al., 1999) of existing and potential users (Figure 4), making it more capable of creating systemic value for the user.

An existing activity of interest and its outcomes are meticulously observed using a HCD approach in order to detect under-explored innovation areas and then set innovation specifications for the design of the future activity while pushing new meanings. A modeling language is provided to break down an activity into (i) archetypal usage situation classes, (ii) assign present and potential activity users into archetypal persona classes, (iii) assign pains and expectations into generalized problem classes and (iv) existing (market) solution classes. RID is a Usage-Driven Innovation (UDI) approach, a new model of designing for usage-driven innovation processes (Figure 5) was proposed by Yannou et al. (2018), extending the FBS model of designing (Gero, 1990). This has allowed RID to be, to our knowledge, the first computerized methodology to implement usage-driven innovation processes.

The RID process (Salehy et al., 2021) works in three stages (Figure 6): (1) Observe today's activity and learn about it by building a cognitive model, (2) Explore this cognitive model and decide the innovation targets, (3) Ideate, design and check that your innovative solution(s) effectively

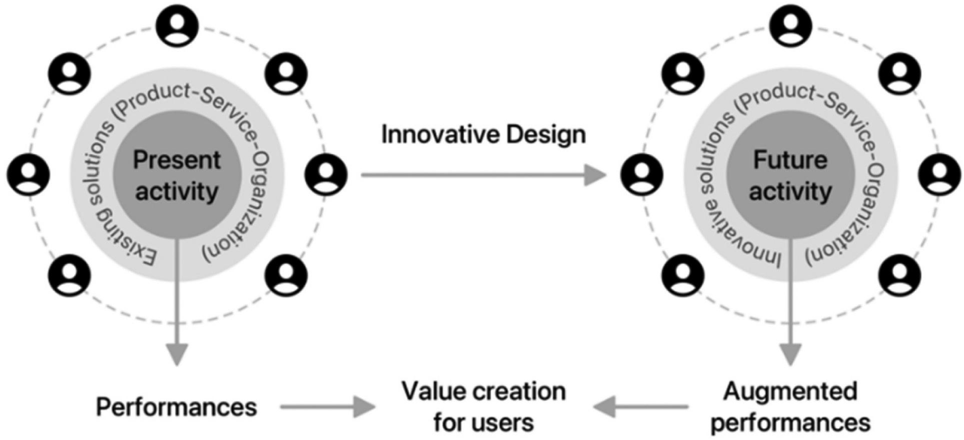

Figure 4. Reference framework for innovative design with Radical Innovation Design.

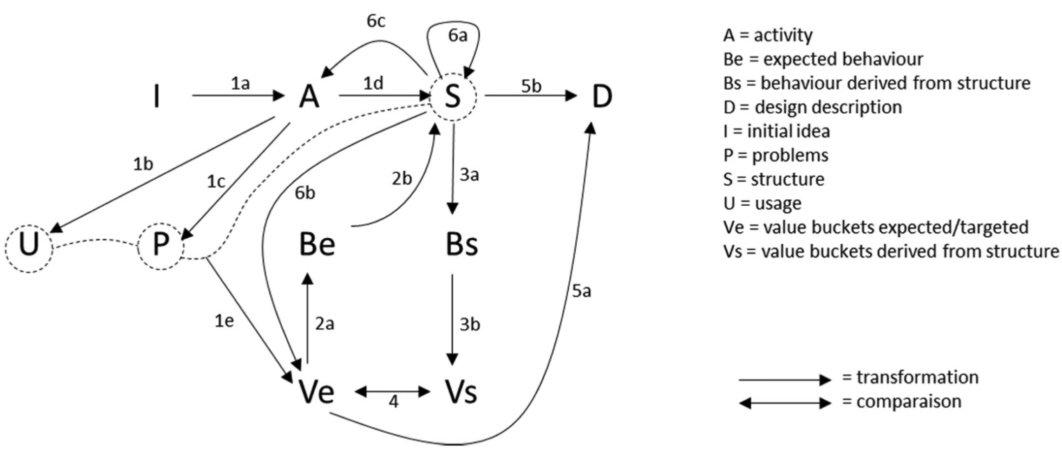

Figure 5. The Usage-Driven Innovation Process (UDIP) model of innovating.

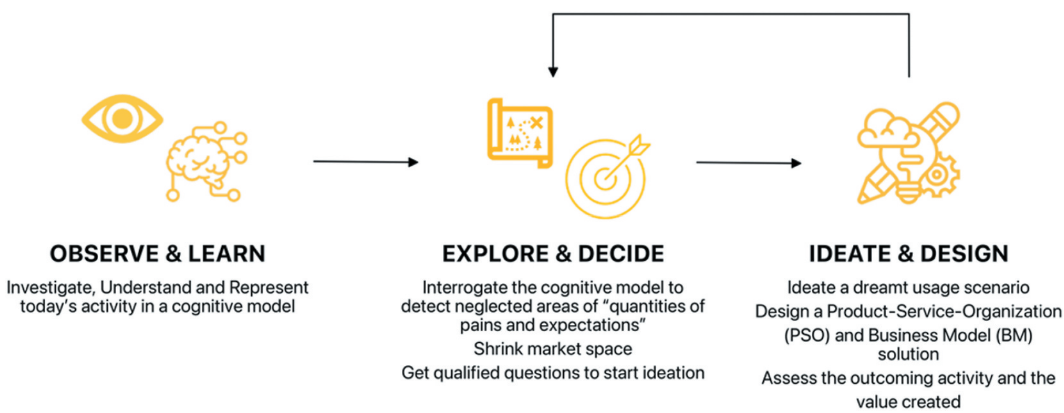

Figure 6. The Radical Innovation Design process of Usage-Driven Innovation.

augment(s) the user's activity. In stage 2, decision-making algorithms are provided to: (i) compare products under their ability to deliver effective service during the representative usage situations of the activity, (ii) highlight value buckets that are under-exploited innovation areas where users live painful situations or unmet expectations, and your competitors tend to be under-effective. In stage 3, a RID creativity tool uses the targeted value buckets as qualified questions for ideating, in attempting to shift any of their characteristics for getting inspiration of shifted situations where the activity effectiveness is high.

In brief, RID appears to be a systematic production process of innovation leads, supported with a digital platform and opens the era where data automatically collected during the use phase of designs can be analyzed for improving the next design generation. In practice a digital platform (see, Figure 7) allows to visualize the different conceptual stages of innovating, to benefit from metrics for making informed decisions, to explore several leads and finally to trace your cognitive reasoning and possibly replay it. In RID (see, Figure 7), designers first explore and design the problem, then design and explore the solution, looping until the problem/solution couple is satisfactory in terms both of specific value creation for (activity's) users and profit for the company.

For the next decade, we can think of another type of smart innovative design process representation like the one of Figure 8. New products and services should now be systematically designed to adapt to the uses of each user but should also be able to improve with the knowledge of the uses of all. They should also be designed to enable the circular economy. And finally, they should be designed to adapt as well as possible, and over time, to the other systems with which they are connected in their operation (example of VtoX functions of connected car to allow a car to communicate with each other or with VtoX road infrastructures). These three features are still poorly developed. However, there are promising leads such as bio-inspired or other ideation

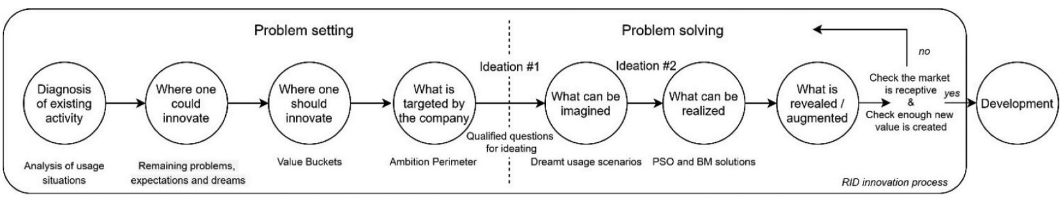

Figure 7. The different conceptual stages when innovating with the RID digital platform.

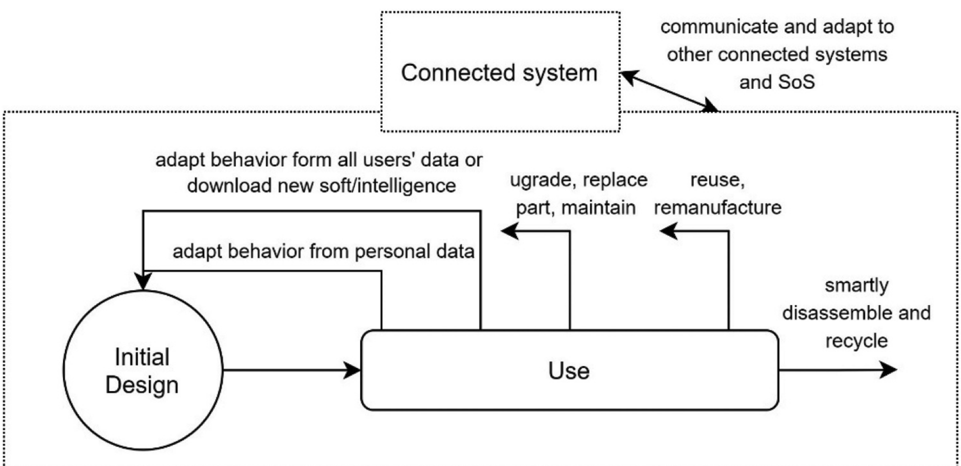

Figure 8. A smart innovative design process representation for the next decade.

mechanisms for eco-innovating better design concepts (Tyl et al., 2014), and design approaches from systems engineering for designing a product-service system in a system of systems context (Hein et al., 2018).

3.2.6. Co-creative designing with AI (Kazjon Grace)

This last decade has marked a turning point in the application of AI to creative designing, along with virtually everything else. Creative AI, usually defined as the computational generation of artifacts like text, images, or other artistic or designed objects, has exploded over that same period. Once a niche exploration of future possibilities, the application of AI to creative domains is now a common advertising refrain for new algorithms – many of which can now create works indistinguishable from that produced by humans (Bessette et al., 2019).

The question for design creativity researchers over the next decade is whether these advances – from 'deep fakes' to computational poetry – are a reservoir of untapped potential for computational design, or merely very exciting tech demos. That question will likely pivot on whether it is possible for designers and artists to meaningfully collaborate with these technologies, as opposed to just hitting a button and seeing what happens. If these technologies can help designers with the detail, then they will be a welcome, if perhaps disappointing, boost to productivity. But that is not the true promise of designing with AI: the true potential comes from the possibility of AI assistance in the conceptual phase of designing. If human–AI collaboration becomes a regular part of the conceptual design process, then future creative workplaces, from engineering to graphic design to medicine, will feature AI that can enhance and expand on human contributions. This vision has been referred to as 'co-creative AI' (Davis et al., 2017).

That vision, however, faces an obstacle: to collaborate conceptually requires negotiating a shared understanding of a problem space that's not yet fully formed. That essential cognitive fluidity has many faces in design research, including reflection-in-action (Schon, 1983), design as coevolution (Poon & Maher, 1997), frame innovation (Dorst, 2015), and situated cognition (Gero & Kannengiesser, 2004). In each of those related concepts the core message is the same: conceptual design involves figuring out the problem as much as it involves figuring out the solution. Why is that a problem for creative AI? Because we know from decades of studies with human designers that working with that representational ambiguity requires open and fluid dialogue (Dong, 2005). Thus far, however, co-creative AI is either not interactive at all, or can be interacted with only in inflexible and predetermined ways.

Dialogic interaction, by which I mean both iterated and responsive interaction through the exchange of design artifacts and the more traditional definition of iterated interaction through language (i.e. about, but external to designed artifacts), would be a fundamental paradigm shift for computational design tools. The conventional wisdom for any tool is that it should be maximally unobtrusive, augmenting but not interrupting, evoking Heideggerian ideas of being 'ready-to-hand'. But designing tools for unobtrusiveness precludes any system that can take its own initiative. Perhaps existing interaction models can be repurposed, or perhaps it's time for something completely different.

The future potential of AI assistance in design creativity suggests, at least to me, three key research directions for the field:

(1) How can we build co-creative AI systems for designers: systems that can fluidly communicate about emerging designs, both in the problem and solution spaces?
(2) How can these technologies be designed such that they integrate with and augment the cognitive processes of human designers? This question spans both the AI question of how they should operate and the user experience design question of how they should be encapsulated into products and services.
(3) What are the impacts of co-creative AI on the cognitive behaviors of interest to researchers of design cognition: how do they influence creative self-efficacy? Fixation? A sense of flow?

3.2.7. AI and creativity as an emerging topic for the design research (Mario Štorga)

Creativity and creative problem-solving skills are of crucial importance for designers and the design process. With the rise of AI, there is much chatter and concern that machines in various industries will take over jobs, but design creativity is a realm where machines will least likely replace humans. That said, there are still vast opportunities where AI can and ultimately will help designers optimize, facilitate and expedite creative design processes and enhance creativity and innovation.

General feeling expressed by experts and practitioners (Pfeiffer, 2018) is that AI may give creative workers more time to be creative. AI could optimize the creative processes by streamlining content output and unlocking new mediums and functionality. Particularly when it comes to the tedious work required to execute the ideas that AI could take over, freeing up the creators to spend more time ideating around creative problem solving and design thinking (Sharma, 2018).

Another exciting way how AI could augment human creativity and innovation is by generating novel patterns and designs for humans to engage with. For example, generative design software can capture and process information provided by designers, including various criteria for creating. The result is a novel source of inspiration – an assortment of ideas that the designer would likely not have even come up with without AI (Breakstone, 2019).

The above-described application of AI will not undermine the basic principles of design thinking (abductive and iterative). Still, it will enable us to overcome past limitations (in scale, scope, and learning) of design processes conducted by humans. In that context, applying AI in the design and innovation process may lead to more user-centered, more creative, and continuously updated solutions through learning iterations that span the entire life cycle of a product or service (Verganti et al., 2020). The problem-solving tasks, traditionally carried on by designers, could potentially, with the application of AI, be automated into learning loops that think in a radically different way than a designer: AI addresses complex problems through simple tasks, iterated exponentially. As stated in a recent paper from economists at MIT, Harvard, and Boston University (Rotman, 2019), AI's most significant economic impact could come from its potential as a new 'method of invention' that ultimately reshapes 'the nature of the innovation process and the organization of R&D'.

Consequently, future research on AI and creativity in design is one of the most exciting emerging topics for the design research community requiring multidisciplinary approaches and synergy. It will extend traditional design creativity and innovation research boundaries and may become the most potent integration point of design research and other disciplines. The augmentation of human intelligence with powerful computational modeling and AI tools should, in the end, enable the industry to address the growing complexity of product design, manufacturing, and the value chain. The topics like design information enrichment, support for design empathy, design practice, and subjective response or AI-augmented design activities are areas where we expect to see research contributions soon (Liao et al., 2020).

3.3. Design outcome

3.3.1. Ethical and design challenges in the transition from creativity tools to AI partners (Mary Lou Maher)

Computing has affected all aspects of all research fields. We are able to collaborate across time and place in virtual meetings with much more facility, partly due to the COVID-19 pandemic forcing us to become more tech savvy in virtual meetings. We are able to collect and learn from very large datasets with the advances in data science and Artificial Intelligence (AI). We are experiencing more human-like interaction with search engines and recommender systems with advances in interaction modalities such as conversing and visual exploration. We are starting to think about interactive systems as partners rather than tools. We talk to Siri and Alexa. We interact with generative AI to inspire us.

In the research field of design creativity and innovation, advances in the ability of AI and interactive computational systems for enhancing human creativity has led to two new research challenges since this journal was started:

- What are the ethical and consequential challenges in the transition from computational tools to AI partners in creative systems?
- What role does interaction design/HCI research play in enabling co-creative systems?

Research in designing computational systems that are creative in their own right currently focus on AI ability. AI methods have been developed that are able to generate convincingly human-like creative content in various domains (NeurIPS, 2019; Nobari et al., 2021; NPR, 2021). Similarly, co-creative systems, sometimes called mixed initiative creative interfaces, are now producing partnerships in which humans and AI work together on creative outcomes (Deterding et al., 2017; Kantosalo et al., 2014; Karimi et al., 2019). The challenges facing researchers with this increased ability of AI to be creative and to collaborate with humans on creative tasks include the limited understanding that designers and users have in how the AI models work; the need to improve understanding of the impact of AI contributions on cognition as well as creative outcomes; the need for more comprehensive interaction models that enable trust; and the imperative for ethics in the application of AI models on large datasets that may have copyright issues and bias.

In human–human co-creativity, as well as in human-AI co-creativity, creative partners accept suggestions into the space of possible creative products (Swartjes & Theune, 2009) and both the human and the computer are influenced by each others' contributions (Davis, 2013) culminating in sharing creative responsibility over the resulting product (Kantosalo et al., 2014). This new paradigm is characterized by the mixing of computer and human initiative (Yannakakis et al., 2014) in the middle of a continuum between human creativity and autonomous computational creativity (Deterding et al., 2017). Improving the interaction design with more human-like abilities for conversing and embodied interaction leads to more engaging AI collaboration (Abdellahi et al., 2020; Lee et al., 2020). Despite powerful generative AI methods becoming more and more accessible for designers of creative systems, we still know relatively little about designing interactive generative AI, how to design creative user experiences around them, and the ethical challenges defined by the open-endedness and reuse of creative work. Even less is known about the long-term effects of the new technology to the creative practice of artists, designers, and laypersons; the role interactive generative AI-based systems will eventually take in society, and what kind of regulations will eventually govern the space of design in this area. The advances in the ability of AI to contribute to and enhance our creativity is an imperative to examine the social and ethical issues that should be incorporated in the AI models and to ensure that interaction design leads to trustworthy ethical co-creative systems.

3.3.2. Perspectives on design creativity and innovation research – 10 years later (Panos Papalambros)

In the journal's aims and scope we have stated that 'The journal aims to not only promote existing research disciplines but also pioneer a new one that lies in the intermediate area between the domains of systems engineering, information technology, computer science, social science, artificial intelligence, cognitive science, psychology, philosophy, linguistics, and related fields' (https://www.tandfonline.com/toc/tdci20/current).

This 'intermediate area' where diverse disciplines intersect can, more often than not, become a 'no-man's land' – what the dictionary defines as 'an anomalous, ambiguous, or indefinite area especially of operation, application, or jurisdiction' (https://www.merriam-webster.com/dictionary). Happily, over the past decade IJDCI has demonstrated that this area can indeed be populated with high-quality research and practice contributions from diverse knowledge domains. In this spirit, I would put forth three challenges to design creativity and innovation that the community will need to address so that we further strengthen IJDCI's 'intermediate area'.

The first two challenges have been posited already in IJDCI editorials, namely, the roles of artificial intelligence and neuroscience in design creativity and innovation (Gero, 2020; Goldschmidt, 2019). Regarding artificial intelligence, the questions tend to be more around machine-human co-creation. I suspect that the question of creativity by machine alone will take more central stage, making the question of what is the (remaining?) role of humans a pressing one. We can retreat to a troglodyte posture and assert that machines will never match us humans but that will not stop the evolution of machines. Regarding neuroscience, there is clear evidence of the links between brain electrochemical processes and creativity events as recognized by more traditional behavioral science. While current understanding of causality beyond documenting observational correlations of, say, brain images is still quite limited, we can expect that this understanding will increase substantially. At that point, we will face more urgently the question of how this understanding can be used not (just) to enhance human creativity but literally to induce it. Like in the case of artificial intelligence, questions about what constitutes a creative designer will become pressing, not just in theoretical research but more so in education and practice. Should we be imagining a race between creative machines and drug-turbocharged humans as to who is the most creative designer?

The third challenge is answering the increasingly relevant question 'Should we create this in the first place?' where 'this' is whatever design solution we may create to satisfy the perceived 'need, want, or desire''of the designer's 'customer, client, user, … '. We have reached the point of living and designing in a designed world. Whatever new we bring into this world through designing may have profound impact beyond our initial design intent. While in the past we had an awareness of this impact, this awareness was manifested in a rather vague way – think climate change and automobile design in the 1920s – or an idealistic way – think designing of weapon systems for individual or mass destruction at any point in time. Today design creativity may provide a clear and present danger for the designed world. I doubt that teaching ethics or adopting ethical professional standards will do much in addressing this challenge – we have been doing this for quite a while. Perhaps including the question 'to create or not to create' as a required element of the creative design process and making it part of the designer's culture will have a more lasting impact.

3.3.3. Integrating the potential of (big) data to boost creativity in design and face the environmental challenges (Niccolò Becattini)

If we look back at what the members of the editorial board of IJDCI expected to be the focus of the research on design creativity and innovation ten years ago, the evidence show they were just partly right with their forecast and intuitions. Since then, some contributions in the journal addressed still unsolved issues, such as the effectiveness of stimuli and their sources to leverage analogical thinking (e.g. Jia et al., 2020; Viswanathan & Linsey, 2013). Other researchers tackled creativity killers, such as fixation (e.g. Crilly, 2018) and, as the other side of the coin, it is not surprising that the measurement of creative performance (e.g. Borgianni et al., 2020) received similar attention. Except for the computational models of creativity (e.g. Grace et al., 2015), what did not appear in the previous editorial, but that now emerges as an already well-established topic, is the role of technology as a support for creative thinking in design (e.g. Cascini et al., 2020: Masclet et al., 2021). Likewise, the importance of the social side of designing was underestimated 10 years ago, as the terms 'collaboration' and 'co-design' appeared just once or twice, while now this is necessary for many academic and professional realities (e.g. O'Hare et al., 2020). In this perspective, we can expect that these driving forces will continue shaping the next steps of design creativity research and the related initiative for innovation. However, the recent changes in the context might suggest that new research directions will open up.

On the side of opportunities, the increasing functionalities of ICT tools and the improvement of Artificial Intelligence are already suggesting 'nascent directions for design creativity research' (Gero, 2020). Their capability to process huge amount of data and extract relevant element to inform designers' activities offers unprecedented chances to stimulate their creativity. In addition, affordable and noninvasive technologies to explore the designers' mind, such as fNIRS (Shealy et al., 2020) and EEG (Li et al., 2021), might enable the development of smart companions that actively foster designers' creativity at the right time.

On the side of challenges, the climate change is the other contextual factor that can significantly affect the definition of goals for innovation and therefore have an impact on design creativity and design creativity research. These problems typically requires a multidisciplinary approach that interconnects the environment with the economy and the society. We can expect that the battlefield for a sustainable future should be the whole planet and not just the desk of designers, as everybody's contribution is needed to address these highly demanding challenges.

As design creativity researchers, we should go on researching and developing creativity boosters (methodologies, methods, conceptual and technological tools) and measure their effectiveness with appropriate evaluation metrics. However, given the above challenges, the focus has to be on methods and tools for creating eco-friendly solutions (Maccioni et al., 2021) and generating innovative strategies to correct the (mis)behaviors that brought us on the verge of disaster (e.g. Cash et al., 2017). Therefore, to enable this, we should also research approaches that engage the society and foster the collection and processing of (behavioral) data about the use of the solutions we contributed to develop with our creative methods and tools (Montecchi & Becattini, 2020). We need to know what did not work well in our previous designs and use these information, with appropriate representations (Montecchi & Becattini, 2021), to stimulate designers' creativity and inform their activities if we want to shape a more sustainable future.

If we do not use our creativity for our own survival, then, for what?

4. Design creativity and innovation: education

4.1. Design process and activities

4.1.1. Creative environments: the role of the studio in design activity (Hernan Casakin, and Andrew Wodehouse)

Creativity is an intrinsic but inconsistent human characteristic that flourishes in favorable conditions. As a highly desirable trait in relation to conceptualization and the delivery of new insights, its promotion and enhancement in relation to design has resulted in a range of theoretical models on its cognitive manifestation, as well as procedural methods and tools to structure activity. The provision of a social, collaborative, informative space is an accepted part of the creative working practices of designers: the design studio. In learning about creative practice, exposure to this environment is a fundamental experience of schools and departments of design. A systematic literature review of design creativity in the architectural design studio surveyed over 700 papers to understand the role it plays in underpinning creative working (Casakin & Wodehouse, 2021). While the review was grounded in the architectural studio, it can be considered in relation to how creativity is supported in design educational settings in general.

Extant research on the most relevant topics in the field in the past 10 years can be organized under the following five categories: i) Pedagogy, addressing aspects concerned with teaching creativity in the architectural design studio context; ii) Cognitive approaches, focusing on design thinking issues; iii) Interaction and socialization, centering on how teams share and communicate design knowledge; iv) Traditional and virtual tools, dealing with access, representation, use and manipulation of information; and v) Measuring ideation and creativity, addressing the assessment of creative processes and outcomes. Exploring these issues highlighted several interesting dichotomies in relation to the typical design studio setting: it is largely collaborative whereas encouraging individual expression; it welcomes the use of a variety of inspiration sources as remote stimuli to deal with problems associated to a context of established typologies; it is well-suited to the use of cutting-edge visualization technologies, but largely relies on conventional sketching and drawing practices; and increasing structure is recommended to support creative activities despite the recognition of a need for non-prescriptive, individual reflection and metacognition in relation to the design process.

In the coming 10 years, a fundamental challenge for the creative design studio not only in architecture but in other design domains will be to continue developing both digital and virtual environments that could emulate and even improve the advantages of teaching in this environment. Indeed, in the era of a global pandemic, there is an opportunity to identify and meet new needs and requirements such as remote distance design studio learning. In this regard, exploring how to support the flow of communication, information exchange and interaction among designers is critical. Research related to the development of more robust digital tools to better (re)present, integrate, and manipulate 2D and 3D information may contribute to this end. Another promising direction might consist in developing further digital libraries containing design information, i.e. design precedents and typological knowledge, but also remote domain stimuli and design strategies in support of creativity during the different phases of the design process. Group interactions during the design studio critiques will benefit from such enhancements, and may aid in issues concerned with team-based problem-solving.

While a progressive understanding of creativity continues, findings from other domains such as biology (biomimetics), artificial intelligence, and neuroscience are yet to be fully investigated in the design studio. Emerging topics from these promising fields will contribute to inform future cognitive models and tools in support of creativity. Any new approaches are still required to be contextualized in such a way that they can support the dynamic nature of this environment that is so closely linked to collaborative creative behavior.

5. How to get a good idea in science, art, design,–and Life (Barbara Tversky)

The core challenges in creativity, innovation, and design never change: think broadly (divergent), think deeply (convergent). Reduce fixation. Then a big jump to: Think out of the box, Think different. But how? And how to explain in 500 words? Here, some organized rubrics, to be enlarged with real research and real examples. In the meantime, no stealing!

Fixation happens when the mind goes round and round in the same rut, another old problem, one at the foundation of memory as well as creativity: stimulus-response associations. Every upside has a downside. For learning, you want to strengthen associations. For innovation, you want to weaken them. The fix for fixation: to form new associations, to get out of the rut, find new stimuli.

Wander

Life is constant flux, just wait, new stimuli come by themselves

Wandering in time, Incubate. The brain prunes distractions and finds essences

Wandering in the World

Wandering in the Mind

Wandering with Other Minds

Wandering might free you from fixation, but it is haphazard, bringing in stimuli that may or may not be productive. Wandering with a plan, a mind-set, a purpose, is likely to be more productive than random wandering. That’s called play.

Play

Wander in a relevant world

Play with other minds

Find similarities and analogies, of surface, of structure, of process, of action, of conception, of outcome

Start with an old idea, then: deconstruct & reconstruct

Change Perspective

Take another's

Go abstract

Examine negative space

Focus

Test your idea(s) (more than one is better than one)

Sketch, model, prototype, role play, user test: you think with all your senses and with your actions and with what they produce.

Repeat

Like the instructions on a shampoo bottle: apply, lather, rinse, repeat. For ideas: wander, play, focus, repeat.

Wait, when to stop? When you're done. You'll know. All the pieces will fit together.

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