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A Call for a New Definition

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Design thinking is increasingly used to address more complex, systemic challenges. Yet one of its core elements, prototyping, has been underutilized in these dynamic contexts. In order for designers to make a meaningful impact on complex, interconnected, and systemic problems, we need to expand the way we conceptualize the practice of prototyping. This paper highlights the way prototyping is conceived through academic and industry literature and illustrates the ways the current understanding limits the efficacy of this practice for systemic challenges. A new definition that harnesses practices from design thinking, participatory design, and critical making is proposed. This new approach aligns with the Breaks in Scale theme by demonstrating how microscopic and macroscopic perspectives can coexist. This revised conceptualization unlocks the full potential of prototyping by shifting the focus from validation and evolution to a tool for learning that will help designers to address systemic challenges in ways that are faster, less risky, and more creative than our current approaches.

Keywords: Systems, Prototyping, Complexity, Design Thinking, Wicked Problems

Introduction

If designers are going to make good on our claims that we can have an impact on increasingly complex, interconnected and systemic problems, we need to ensure that our processes are fit for the task. Prototyping, a central part of design thinking, is one powerful, but currently underutilized approach to creating systemic interventions. Design thinking is a human-centered approach to problem solving which has been applied to domains ranging from physical objects to governmental policies (Kelley and Kelley 2013; Brown and Katz 2009). Most elements of a design thinking approach – empathy for stakeholders, challenge framing, generative thinking, and an emphasis on thinking through doing – continue to work for the “wicked” problems that so many of us are eager to address (Norman 2019; Manzini 2015; Buchanan 1992). There are many examples of how design thinking has been used for systemic challenges, and while many of the case studies do mention prototyping, they fail to tease out the nuances of using this practice for more complex contexts (Bjögvinsson et al. 2012; Mintrom and Luetjens 2016; Kimbell and Bailey 2017). Simply put, our approach to prototyping is outdated and insufficient for the systemic challenges that design is otherwise poised to tackle. The prototyping approach designers have used to develop a toothbrush will not help us create interventions in dynamic, interconnected systems. Yet, without a more nuanced understanding of the shortcomings and possibilities of prototyping we will continue to underutilize this essential practice. Harnessing elements of design thinking, participatory design and critical making can help to shift our thinking about prototypes from a contained concept to a tool for learning. Doing so will allow designers to address complex, systemic challenges in ways that are faster, less risky, and more creative than our current approaches.

Public awareness of prototyping has been growing since the early 2000s when design thinking, innovation, and start-up culture became part of a mainstream vernacular. In this context, prototyping was positioned as more efficient way to develop and launch products in a competitive marketplace. The broad notion of prototyping continues to gain currency to this day, but not enough attention has been given to the way this critical skill has been defined (Brown, Katz 2009; Brunner, Emery 2009; Kelley, Littman 2001; Martin 2009). The last several years have seen an abundance of literature on the topic, but despite the fact that many of these texts are solely dedicated to the topic of prototyping, few shed light on the potential for using the practice at the systems scale.

From the practitioner perspective Todd Zaki Warfel's Prototyping (2009) and Kathryn McElroy's Prototyping for Designers (2017) cover many of the key aspects of the practice as it applies to design of software, interfaces, products and services. While some of the principles they illuminate can be applied to prototyping systems, neither of them explicitly mention using prototypes for this purpose. Jane and Mark Burry's (2016) Prototyping for Architects also calls out familiar themes, but, predictably, this work focuses on the practice from an architectural perspective. Rethink! Prototyping (2016) edited by Gengnagel, Nagy and Stark is the culmination of multi-year project that explored the ways prototyping can be reimagined and potentially redefined across several disciplines. Although one of the central themes of this project was to reimagine a definition of prototyping, the work hews closely to object-centric projects in architecture, engineering and product design. Discussions of complex systems are rooted in complex product systems and fail to broaden the definition to a point where the practice can be used to explore unbounded challenges where the constraints are in flux. Works such as Brown and Katz's (2009) Change by Design specifically notes how design thinking is used to address systemic challenges, but they offer little in the way of details about how prototyping plays a specific role in these complex problems. The most comprehensive approaches to prototyping have come from the fields of participatory design, anthropology and critical making (Suchman et al. 2002; Ratto 2011; DiSalvo 2014). Halse et al's Rehearsing the Future (2010), Ehn et al's Making Futures (2014) and Kimbell and Bailey's work (2017) provide examples of how prototypes can be used to explore complex systems, but a more explicit examination of the practice and an articulation of how to employ it are is still necessary if we are to get the most out of this way of working. Given all of this work, there are consistent themes that emerge around the common conception of prototyping.

The current understanding of prototypes

The concept of a prototype is not new. Its use in Europe dates back to the 1600s and comes from Greek "proto" and "typos", which translates into the first form or first of its kind. (Gengnagel, Nagy, Stark 2016). From this early definition we can see the ways the current understanding has been widely interpreted and varied in its definition (ibid). However, in much of the academic and practitioner literature on the subject, several consistent elements emerge (Bødker and Grønbæk 1990; Brown, Katz 2009; Buxton 2011; Calvillo 2010; Chi 2015; Floyd, 1984, Gengnagel, Nagy, Stark 2016; Halse 2010; Kelley, Littman 2001; Kolko 2017; Martin 2014; McElroy 2017; Warfel 2009). How then, are prototypes currently understood today?

- *Prototypes are about speed.* While some prototypes may take minutes and others will take years, the prototype is always a faster mode of exploration than a fully resolved offering.
- *Prototypes mitigate risk.* They help designers avoid mistakes at later and more costly phases of the product development cycle.
- *Prototypes communicate.* They become a way for the members of a design team, users, partners and others to surface new forms of understanding, misconceptions and ways of thinking that are far more powerful than verbal or visual assets alone.
- *Prototypes are incomplete.* They describe the final product, but they are not finished products in-and-of themselves.
- *Prototypes are instructive.* They help creators learn how to improve upon a design.
- *Prototypes validate.* They help teams understand more about the viability of an idea.
- *Prototypes are iterative.* They follow a linear (albeit often meandering) path from rough idea to a more refined concept.

These aspects of prototypes are beneficial for bounded challenges where designers have an accurate understanding of the context, control over the output, and a modest time savings can translate into a competitive advantage. However, when designing for complex systems and wicked problems, the design landscape looks very different. In the systems context this way of prototyping is deeply inadequate.

Systems, complexity, and wicked problems

The most meaningful challenges we face as a society are systemic in nature. Climate change and racial inequity are some of the most iconic example of this set of problems, but similar intractable, interconnected, dynamic, and highly complex issues are all too common. Global pandemics, homelessness, and the opioid crisis can all be justifiably described as systemic, complex, or wicked. This work draws on the scholarship in the systems and complexity domains in order to illuminate the ways in which the nature of systemic issues expose the limitations of current design thinking processes in general, and, specifically, prototyping. The work of defining systems is beyond the scope of this article and has been thoroughly addressed elsewhere (Bar-Yam 1997; Kurtz and Snowden 2003; Meadows 2008; Senge 2006; Buchanan 2019; Collopy 2019). My intention is to highlight the aspects of systems which make them such a vexing context for our current notion of prototyping. In order to do that, I approach systems from the perspective of a designer who seeks to create change within this pluralistic, daunting, and layered medium. Designers looking to design for complex systems must ask themselves: *How do we prototype when:*

1. *The design constraints are in flux (Senge 2006; Meadows 2008; Ricigliano 2012)*
2. *The range of issues and influences will change with each prototyping iteration (Kurtz, Snowden, 2003)*
3. *We are under intense time pressure (Levin et al. 2012; Rittel and Webber 1973).*
4. *The problem spans mediums, constituencies and disciplines (Manzini 2015)*
5. *There are many stakeholders and each have different perspectives and ideas of what is "right" (Rittel and Webber 1973; Buchanan 2019; Body, Terrey 2019)*
6. *Meaningful solutions require action from distributed groups (Manzini 2019)*
7. *Potential solutions cannot be evaluated in isolation from the context of the challenge (Kurtz, Snowden 2003)*
8. *The challenge cannot be solved, only influenced (Rittel and Webber 1973)*

This set of constraints highlights the radically different landscape of designing for systems. So, then, how can a designer prototype in this context? It is all but impossible if we adhere to a traditional conception of the practice.

The problems with the current definition

Most aspects of prototyping are still effective for exploring systemic challenges. Speed, communication, learning, and risk mitigation are all still highly beneficial. However, in a systems context, the emphasis validation and evolutionary iterations become deeply problematic.

The validation trap

Prototypes are widely acknowledged as tools for exploration, learning, validation, and testing. Unfortunately, a disproportionate focus on validation and testing skews the ways we think about their potential as tools for learning. Christiane Floyd's work, coming out of computer science is foundational and recognizes the value of a prototype as an exploratory tool (1984). By linking learning with prototyping, Floyd opened up space within this practice for discovery and understanding and her influence is obvious throughout the prototyping literature on the subject. Unfortunately, Floyd's view on the educational aspects of prototypes does not go far enough to make it useful in a systems context. Learning, according to Floyd, is focused on the thing itself, and is used to evaluate the success of the concept rather than *also* being used as a way to more deeply understand broader context in which it exists. This drive to substantiate the efficacy of a concept is less problematic in bounded challenges where the context is well understood and stable. But when designing for unbounded, complex situations, a reliance on the validation becomes counter-productive. Rob Ricigliano describes this way of thinking as "self-defeating" for complex systems because it lures teams into responding to complexity with *inflexible*, *short-term*, and *fragmented* mindsets (2015).

The role of validation in prototyping is not inherently problematic, but when the act of prototyping becomes *only* about validation, we fall into a trap that blinds us to the broader context and undermines our ability to use prototypes as a way to quickly explore interventions in complex systems.

The evolution anchor

While the validation trap diminishes learning potential, the presumption of prototypes as evolutionary is equally problematic in the ways it limits our ability to explore systemic challenges in radically reduced time frames. When a solution space is reasonably proscribed, even for complicated problems like creating a self-driving car, an iterative and *linear* approach is sufficient. In those scenarios, a design team has a sense of their final output and they can use each successive iteration to get closer to that goal. Iteration A leads to iteration B which leads to C and so on. The broad consensus is that each prototype builds on the last and, despite some expected dead ends and detours, the path from early idea to more refined concepts adhere to a rough trajectory (Chi 2012; Kelley, Littman 2001; McElroy 2017; Martin 2014). These prototypes follow a *progression* from rough (low-resolution) iterations of an idea to more refined (high-resolution) versions of the solution. Unfortunately, this way of thinking severely limits our ability to prototype minimal risk and time.

To address this issue we need to disentangle iteration from evolution. The two terms are often conflated and it is assumed that each successive iteration will build upon the last. This constrains the creative ways a team can approach an issue and slows down their ability to explore an aspect of the challenge with speed and efficiency.

In order to explain this idea in a more concrete way, imagine a young couple who is considering having their first child. They want to understand as much as they can about the sacrifices and rewards that would come with making such a huge life change. They start by spending time around other couples with young children. After that initial experiment, they decide to look after a friend's child for an evening. In this way, they are increasing the resolution of their prototypes. With each iteration they gain more knowledge and increase their level of commitment. But while these explorations are useful, the couple still has the nagging feeling that some of the knottier questions are not yet answered. How will this affect their relationship? Will things change as it becomes real? What will it be like to experience all of this over the long term? These types of questions will not be answered by more babysitting. The couple has come up against the limits of what they can learn from prototypes that evolve from low to high resolution. In order to continue to gain understanding (without a massive investment or risk) they will need to separate their learning from progressive iterations. They do this in a way that breaks from an evolutionary conception of the prototype. They get a dog.

The prototype (getting a dog) is a non-linear iteration. The dog will never become a child. Despite this, the experience of getting a dog can teach them far more about how the system (their relationship) will respond to a significant change that they would not ever be able to fully comprehend with theory and planning alone.

In this case, the couple has managed to get more learning about the system as a whole, without a major increase in risk and commitment associated with prototyping in a progressive, linear way. The fact that the dog is decoupled from a child in terms of output, but deeply linked in terms of what it can teach them, means that this act of prototyping can be far more rapid and instructive than if they were focused on the output of solution (in this case, a child). By exploring the challenge in this way, the act of prototyping can be far more nimble and responsive than prototypes that follow a progressive path. That speed and flexibility is critical when dealing with complex systems.

Tramp bikes as an illustration

So is it really possible to think of prototyping in a way that could be used to address super wicked problems? Oddly enough, the way BMX freestylers learn tricks can be a useful illustration of how we might have an expanded understanding of this practice (Maiorana, 2014).

Freestyle tricks are the types of athletic feats one might see at the X-Games where riders launch themselves off a ramp, flip the bicycle in seemingly impossible orientations, and then land. These tricks are an instructive analog as we think about creating products, services, experiences and designing for systems. They are highly complex, dynamic, incredibly risky, and impossible to do half-way.

In order to learn how to do these manoeuvres, BMX riders developed a clever solution called a "tramp bike". Like many low-resolution prototypes, the tramp bike is modest enough to escape notice. It is a bike frame with no wheels, pedals, chain, or brakes (https://en.wikipedia.org/wiki/Tramp_bike). In isolation, the bike cannot be ridden. However, when it is placed on top of a trampoline - the name was shortened to tramp - riders can bounce up and down in order to get enough clearance to explore a variety of manoeuvres. The bike exists only to support a rider's efforts to learn a new move. Put another way, the tramp bike allows the rider to *prototype* a trick.

On a BMX track, a rider can only attempt one jump every few minutes. With a tramp bike, she can easily attempt 200 tricks during that same time. In doing so, she has simulated the most critical aspect of the actual trick, the moment she is in the air. This concept draws on the notion of the leap of faith assumptions made popular by *The Lean Start-Up* (Reis 2014). This narrow focus allows the BMX rider many more opportunities to learn about the complex and nuanced interaction between her movements and those of the bike. With this rapidly acquired understanding, she is prepared to attempt the actual trick in far less time than if she had simply attempted the full trick from the start.

The tramp bike is a process innovation that supports learning by allowing any BMX rider with little more than an old bike and a trampoline to quickly perfect and explore dangerous tricks through increased iterations with less chance of getting injured. Without a tramp bike, the rider needs to jump high enough to orchestrate an elaborate manipulation of the bike and then position it underneath her before she lands. The physics of this trick make this impossible to do slowly but separating the issue of clearance from the idea of riding a bike unlocks tremendous progress in one part of the system. Once the rider has figured out this portion of the challenge, she can reintegrate that learning with the elements necessary for the complete trick. All of these benefits are realized because the riders have decoupled the most challenging parts of the trick from the full maneuver.

The tramp bike is instructive as we return to our definition of prototyping. It serves as an example of how we can prototype in a way that allows for the rapid exploration of dynamic design contexts. To do this we need to rethink how we define the practice.

Prototyping: A more expansive definition

In order to utilize prototyping to explore complex challenges, we need to recast the prototype as *any intervention that enhances our ability to learn about an aspect of a design challenge with minimal risk, investment, and time*. While this expanded definition encompasses existing notions of prototyping, it also contains several distinctions that make it far more appropriate when thinking about designing for complex systems.

The first significant departure is that a prototype can be ***any intervention.*** This counters the assumption that prototypes manifest elements of a completed concept and expands the possible forms a prototype may take. This shift can be incredibly liberating and makes it possible for prototypes to be as modest as a meeting invite or music selection. These everyday activities become prototypes when they are crafted with intention and a goal of learning. While this practice in and of itself may not be so rare, it is far less common to refer to designed interpersonal experiences as prototypes. Yet, that is precisely what happens at the d.school, the Hive at the Claremont Colleges and the growing number of organizations where the role of prototyping is used explicitly as a way to explore culture and relationships. By expanding what we think of as constituting a prototype, we increase the creative ways in which this practice can be applied.

Although learning is widely recognized as part of prototyping, the scope of that inquiry is almost always limited to the designed artifact. In contrast, when ***enhanced learning*** becomes the reason for the prototype, we invert the traditional dynamic from *learning (as a way to make a better artifact)* to *artifact (as a way to get better learning)*. This shift still accommodates an exploration of the artifact but, critically, it expands the scope of inquiry in ways that are essential for unbounded contexts.

Seen in this way, the prototype moves from a discrete object to something with a far more fluid sense of utility. This expanded thinking about prototypes has been addressed in much of the related work from the field of participatory design. In *Working Artefacts: Ethnomethods of the Prototype,* Lucy Suchman counters the object-focused aspect of the practice and highlights the ways they can also be used to understand an emerging sense of context (2002, 172). Suchman's description of "mutual learning" relates to the participant's practices, but it is significant in the ways it highlights the role of the prototypes as an intermediary object that helps to transmit information between the designers, users, and contexts. In a similar vein, Carl DiSalvo addresses this issue in his work on critical making, noting that prototyping "is dialogic in that its structure is one of exchange and its purpose is the discovery and elucidation of the conditions or factors of a design."(2013, 23). Suchman and DiSalvo each highlight the ways prototypes can be used in service of something greater than the evaluation of the object itself, but it is worth noting that their work also references a transmissionary quality that is essential for prototyping in more dynamic domains where *sensing* and *responding* are necessary for effective action (Snowden and Boone, 2007).

The scale and complexity of systemic challenges make it impossible to quickly explore within a complete design context. By highlighting that a prototype supports the exploration of ***an aspect of a design challenge,*** this new definition relaxes the constraints implied by progressive iterations and offers the team additional license to explore the broader context. Prototypes can then be used to help a team define or redefine a challenge. Although this aspect of prototyping is not widely covered in the design thinking literature, it is well practiced in the d.school's teaching. It is most apparent during the testing phase when students are challenged to use prototypes to simultaneously evaluate two criteria: *How well are we solving the problem?* and *Are we addressing something worth solving?* These two questions bring focus to the solution and the frame (Klebahn, Utley, Segovia 2014). While the first question is common in prototyping, the second helps designers avoid getting too wedded to their solution and creates space for continued learning about the user, context, and systems in which it exists.

The final piece of this proposed definition, ***minimizing risk, investment and time,*** adheres closely to the current understanding of the practice, but there are a few key distinctions that make these elements better suited to wicked problems.

In a systems context the scale of problems and far-reaching capacity of solutions mean that the role of ***risk*** is much greater than in more bounded challenges. While much has been written about the ways prototyping can reduce costs and investment, far less has been shared about how to limit liability for the broader participants and users. A systems context requires prototypers to minimize potential negative impacts to a community by creating what Snowden and Boone describe "safe to fail" environments (2007). To this end, systems prototypers must reduce risk not only for their business, but for the broader community of stakeholders, much the way participatory designers have employed the concept of *infrastructuring* (Karasti, 2014; Hillgren, Seravalli and Emilson 2011).

Prototyping with as ***little investment*** as possible limits the potential costs from the perspective of the design team and is widely addressed in existing literature, but limiting investment also has implications for who gets to design. It makes prototyping more inclusive by making *creativity*, not capital, the dominant prototyping currency.

As an example, we can look at the efforts of Rebar in San Francisco. They were curious about the idea of transforming parking spots into small public spaces. To explore this potential in a traditional way a team would likely develop a report filled with costly analysis and lobbying efforts aimed to sway the numerous stakeholders who would need to approve the project. Few people have the resources to take on such an ambitious and time-consuming challenge. Rather than follow that path, Rebar utilized a prototyping approach. Their only investment was a pocket full of quarters, sod, a potted plant and a bench. They paid for the parking space and prototyped the first parklet. The modest prototype in 2005 quickly gained traction across the world and is now a global phenomenon (Schneider 2017).

The Parklet example demonstrates the ways in which creativity can empower domain outsiders to explore and realize potential futures. In doing so, they embody what Ezio Manzini describes as design-*bricoleurs* who "reassembl[e] preexistent objects" and "decontextualize" and "reinterpret" them (2019). This approach also addresses one of the shortcomings of coalition building efforts that rely on engagement from "powerful strangers" (Emilson, Hillgren 2014). The limited investment allowed Rebar to do more with less. By decreasing their reliance on support from those in power, they were able to get a first version off the ground, which built momentum and influenced the local government in a way that is unlikely through traditional channels.

The final piece of the revised definition, ***speed*** remains a critical part a prototyping practice. Our ability to quickly explore solutions and contexts is particularly pertinent for systems challenges and super wicked problems like climate change or the current global pandemic where there is limited time in which we can take meaningful action (Levin et al. 2012; IPCC 2019). Faced with these dire situations, designers must be able to maximize what David and Tom Kelley describe as "cycles of learning" in increasingly compressed timeframes (2013).

Implications for a new definition

Adopting this more encompassing view of prototyping will require some shifts in the way designers approach this practice. It calls for ways of working that allow for seemingly conflicting approaches to co-exist.

Prototyping requires humility. Unfortunately, hubris is far more common than humility in so many "innovative" organizations where prototyping is synonymous with mottos like "fail fast and break things"(Taneja 2019). Prototyping is an act of power. Designers need to see it as such and employ this practice with a sense of responsibility (Manzini 2015). Diego Rodriguez sums it up in this way, "Prototype as if you are right. Listen as if you are wrong"(2009). Rodriguez's directive challenges designers to recognize their limitations and use prototyping to both put forth an idea and step back to see what they are learning about the system through their efforts. Put another way, if designers can maintain a humble posture, the prototype can then be used as more of a dialogic tool (DiSalvo 2014). With this approach, designers can both advocate and inquire, which support conversations infused with learning that are a necessary part of institutional and systemic change (Senge 2006).

Prototyping requires curiosity. A sense of curiosity is a well-established quality of effective learners and creative individuals (Gruber, Gelman, Ranganath 2014; Hagtvedt et al. 2019). Designers' sense of inquisitiveness often manifests in the why and what if and how questions, outlined by Warren Berger, but we often lose the depth of that interest after arriving at a solution (2016). To prototype in highly ambiguous, uncertain contexts, it is essential for designers to stoke curiosity and continually revisit the why and what if questions.

Prototyping requires responsiveness. As central as learning is to the revised definition of prototyping, it only matters if the designers continue to create interventions that are imbued with this increased understanding. That is, the prototyper must be responsive. Manzini describes this way of working as "generating a positive circle between action and reflection" (2015). In a systems context, where information about the design challenge is continually unfolding, an ability to respond is far more critical than traditional contexts where sufficient understanding of the context allows planning to take more of a central role.

Prototyping requires commitment. Systems are always in flux. They are entities with a past and a future (Senge 2014). Yet we often design as if the current moment is the only one that matters. This approach is akin to assuming a ballerina can fly because we see a picture of her during the middle of a leap. When prototyping for systems, we need to commit to the act of prototyping, rather than expect that we have the right answer (or the right direction) without taking the time to allow the system to respond. Snowden and Kurtz note that in "un-ordered" environments, "instead of attempting to impose a course of action, leaders must patiently allow the path forward to reveal itself. They need to probe first, then sense, and then respond"(2007). These three actions could easily be another way of describing what it takes to prototype with this expanded definition. But to do so, a prototyper needs to be committed to the very different postures of proposing action and evaluating and then responding with a more refined understanding.

This process takes time. In this regard the prototyper must again hold two very different ways of being. On the one hand, she must maintain a sense of speed and urgency, moving as fast as possible to increase her understanding, but she must do so in a way that does not come at the expense of the dialogical aspects of the process.

Conclusion

Prototyping is as necessary as ever, but the popular conception is far too limiting to address our most pressing issues. By proposing a more expansive definition, I hope to highlight the assumptions and shortcomings of the current understanding so that we can evolve this practice to meet the needs of the growing set of complex, systemic challenges.

The survival of our species is dependent on our ability to accomplish unprecedented feats of collaboration, engineering, and behavior change in a limited time. It will necessitate the ability to act quickly, while listening and responding with a sensitivity to context and communities. Incorporating these concerns, a systems prototyper should be designing experiments that shed light on a possible path forward and illuminate the larger context and potential alternatives. The ability to decouple an intervention from the complete solution is one way to do this. These efforts can create tremendous learning in dramatically reduced time frames, but the insights they yield must be evaluated with a critical lens that takes into account the distinctions between contexts.

Risk can never be fully retired. At a certain point, the decoupling that yielded speed during prototyping must be reintegrated into the larger context; the BMX rider tries her trick on the track, a product team invests in tooling, and a policy team launches at scale. These steps come with an unavoidable sense of risk, but it will be greatly reduced by the prototyping in a way that brings learning and action into the forefront of this practice.

References

Bar-Yam, Yaneer. (1997). *Dynamics of Complex Systems*. Studies in Nonlinearity. Reading, Mass: Addison-Wesley.

Berger, Warren. (2016). *A More Beautiful Question: The Power of Inquiry to Spark Breakthrough Ideas.* Kindle Edition. New York: Bloomsbury Publishing USA.

Bjögvinsson, Erling, Pelle Ehn, and Per-Anders Hillgren. (2012). "Design Things and Design Thinking: Contemporary Participatory Design Challenges." *Design Issues* 28 (3): 101–16.

Bødker, S., & Grønbæk, K. (1992). Design in action: From prototyping by demonstration to cooperative prototyping. In Greenbaum, J., Kyng, M., (Eds.) *Design at Work: Cooperative Design of Computer Systems* (p. 218). L. Erlbaum Associates.

Body, John, and Nina Terrey. (2019). *Design for a Better Future: A Guide to Designing in Complex Systems*. Kindle Edition. New York: Routledge.

Brown, Tim, and Barry Katz. (2009). *Change By Design: How Design Thinking Can Transform Organizations and Inspire Innovation*. New York, NY: HarperCollins Publishers.

Brunner, Robert, and Stewart Emery. (2009). *Do You Matter? How Great Design Will Make People Love Your Company*. Upper Saddle River, N.J: FT Press.

Buchanan, Richard. (1992). "Wicked Problems in Design Thinking." *Design Issues* 8 (2): 5.

———. (2019a). "Systems Thinking and Design Thinking: The Search for Principles in the World We Are Making." *She Ji: The Journal of Design, Economics, and Innovation* 5 (2): 85–104.

———. (2019b). "Surroundings and Environments in Fourth Order Design." *Design Issues* 35 (1): 4–22.

Burry, Mark, and Jane Burry. (2016). *Prototyping for Architects*. London: Thames & Hudson.

Buxton, Bill. (2011). *Sketching User Experiences: Getting the Design Right and the Right Design*. Nachdr. Amsterdam: Morgan Kaufmann.

Calvillo, Nerea. (2010). "Limn: Infra(Proto)Types In the Air." *Limn*. December 20, 2010. https://limn.it/articles/infraprototypes-in-the-air/.

Chi, Tom. (2012). "Rapid Prototyping X." Presented at the Mind the Product 2012, December 5. Retrieved August 2, 2020 from https://www.slideshare.net/mindtheproduct/tom-chi-rapid-prototyping-at-google-x-mindtheproduct-2012?from_action=save.

———. (2015). "Tom Chi on Rapid Prototyping | Startup Accelerator | SU Labs." Singularity University, October 14. Retrieved August 2, 2020 from https://www.youtube.com/watch?v=OTy1k6Mb7_M.

Collopy, Fred. (2019). "Why the Failure of Systems Thinking Should Inform the Future of Design Thinking (06.07.09)." *Design Issues* 35 (2): 97–100.

DiSalvo, Carl. (2014). "Critical Making as Materializing the Politics of Design." *The Information Society* 30 (2): 96–105.

Doorley, Scott, Scott Witthoft, and David Kelley. (2012). *Make Space: How to Set the Stage for Creative Collaboration*. Hoboken, N.J: Wiley.

d.school staff. (2011). "Bootcamp Bootleg, d.School Method Cards." Hasso Plattner Institute of Design at Stanford University.

Ehn, Pelle, Elisabet M. Nilsson, and Richard Topgaard, eds. (2014). *Making Futures: Marginal Notes on Innovation, Design, and Democracy*. Cambridge, Massachusetts London, England: The MIT Press.

Emilson, Anders, and Per-Anders Hillgren. (2014). “Connecting with the Powerful Strangers: From Governance to Agonistic Design Things.” In P. Ehn, E. Nilsson, R. Topgaard, (Eds.), *Making Futures: Marginal Notes on Innovation, Design, and Democracy*. Cambridge, Massachusetts London, England: The MIT Press.

Floyd, Christiane. (1984). “A Systematic Look at Prototyping.” In *Approaches to Prototyping*. Berlin: Springer.

Gengnagel, Christoph, Emilia Nagy, and Rainer Stark, eds. (2016). *Rethink! Prototyping: Transdisciplinary Concepts of Prototyping*. Cham Heidelberg New York Dordrecht London: Springer.

Gruber, Matthias J., Bernard D. Gelman, and Charan Ranganath. (2014). “States of Curiosity Modulate Hippocampus-Dependent Learning via the Dopaminergic Circuit.” *Neuron* 84 (2): 486–96.

Halse, Joachim. (2010). “Incompleteness as a Norm.” In *Rehearsing the Future*, 3. Copenhagen: The Danish Design School Press.

Halse, Joachim, Brandt, Eva, Clark, Brendon, and Binder, Thomas, eds. (2010). *Rehearsing the Future*. Copenhagen: The Danish Design School Press.

Hillgren, Per-Anders, Anna Seravalli, and Anders Emilson. (2011). “Prototyping and Infrastructuring in Design for Social Innovation.” *CoDesign* 7 (3–4): 169–83.

Huswit, Gary. (2009). *Objectified*. Documentary.

Intergovernmental Panel on Climate Change. (2018). *Global Warming of 1.5°C.*

Karasti, Helena. (2014). “Infrastructuring in Participatory Design.” In *Proceedings of the 13th Participatory Design Conference on Research Papers - PDC ’14*, 141–50. Windhoek, Namibia: ACM Press.

Kelley, David, and Tom Kelley. (2013). *Creative Confidence: Unleashing the Creative Potential within Us All*. 1. ed. New York, NY: Crown Business.

Kelley, Thomas, and Inc OverDrive. (2006). *The Ten Faces of Innovation*. New York: Crown Publishing Group.

Kelley, Tom, and Jonathan Littman. (2001). The Art of Innovation: Lessons in Creativity from IDEO, America’s Leading Design Firm. 1st ed. New York: Currency/Doubleday.

Kimbell, Lucy, and Jocelyn Bailey. “Prototyping and the New Spirit of Policy-Making.” CoDesign 13, no. 3 (July 3, 2017): 214–26.

Klebahn, P., Utley, J., & Segovia, K. (2014). *Design Thinking Bootcamp* [d.school Executive Education].

Kolko, Jon. (2017. Creative Clarity: A Practical Guide for Bringing Creative Thinking into Your Company. Austin: Brown Bear Publishing.

Kurtz, C F, and D J Snowden. (2003). “The New Dynamics of Strategy: Sense-Making in a Complex and Complicated World.” *IBM SYSTEMS JOURNAL* 42 (3): 22.

Levin, Kelly, Benjamin Cashore, Steven Bernstein, and Graeme Auld. (2012). “Overcoming the Tragedy of Super Wicked Problems: Constraining Our Future Selves to Ameliorate Global Climate Change.” *Policy Sciences* 45 (2): 123–52.

Lindström, Kristina, and Åsa Ståhl. (2014). “Publics-in-the-Making: Crafting Issues in a Mobile Sewing Circle.” In *Making Futures: Marginal Notes on Innovation, Design and Democracy*. MIT Press.

Maiorana. (2014). *5 Prototyping Lessons from a BMX Backflip*. [removed for anonymity] Retrieved January 11, 2021 from http://whiteboard.stanford.edu/blog/2014/10/16/5-prototyping-lessons-from-a-bmx-backflip

Manzini, Ezio. (2015). *Design, When Everybody Designs: An Introduction to Design for Social Innovation*. Design Thinking, Design Theory. Cambridge, Massachusetts: The MIT Press.

———. (2019). *Politics of the Everyday*. Section: Life projects as bricolage. Translated by Rachel Anne Coad. Kindle Edition. New York: Bloomsbury.

Marcus, George E., Christopher Kelty, and Alberto Corsín Jiménez, eds. (2010). *Prototyping Prototyping*. Anthropological Research on the Contemporary.

Martin, Roger L. (2009). The Design of Business: Why Design Thinking Is the next Competitive Advantage. Boston, Mass: Harvard Business Press.

Martin, Roger L. (2014). "Strategy Is Iterative Prototyping." *Harvard Business Review*, June, 4.

McElroy, Kathryn. (2017). *Prototyping for Designers: Developing the Best Digital and Physical Products*. First edition. Beijing Boston Farnham: O'Reilly.

Meadows, Donella. (2008). *Thinking in Systems: A Primer*. White River Junction, VT: Chelsea Green Publishing.

Mintrom, Michael, and Joannah Luetjens. (2016). "Design Thinking in Policymaking Processes: Opportunities and Challenges: Design Thinking in Policymaking Processes." *Australian Journal of Public Administration* 75 (3): 391–402.

Norman, Don. (2010). "Why Design Education Must Change - Core77." November 26, 2010. Retrieved on August 2, 2020 from https://www.core77.com/posts/17993/Why-Design-Education-Must-Change.

Ratto, Matt. (2011). "Critical Making: Conceptual and Material Studies in Technology and Social Life." *The Information Society* 27 (4): 252–60.

Ricigliano, Robert. (2012). *Making Peace Last: A Toolbox for Sustainable Peacebuilding*. Boulder: Paradigm Publ.

———. (2015). "Sustaining Peace: Systems Applications Interventions." Conference presented at the AC4 Earth Institute, Columbia University, March 26. Retrieved on August 2, 2020 from https://www.youtube.com/watch?v=9UgyelNq6xI.

Ries, Eric. (2014). *The Lean Startup: How Today´s Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses*. 1. Aufl. USA: Crown Business.

Rittel, Horst W J, and Melvin Webber. (1973). "Dilemmas in a General Theory of Planning." *Policy Sciences* 4: 15.

Rodriguez, Diego. (2009). "4: Prototype as If You Are Right. Listen as If You Are Wrong." *Metacool* (blog). Retrieved on August 2, 2020 from http://metacool.com/4-prototype-as-if-you-are-right-listen-as-if-you-are-wrong/.

Schneider, Benjamin. (2017). "A Brief History of Park(Ing) Day - CityLab." Citylab.Com. September 15, 2017. Retrieved on August 2, 2020 from https://www.citylab.com/life/2017/09/from-parking-to-parklet/539952/.

Senge, Peter. (2014). "Systems Thinking for a Better World." Conference Keynote presented at the Aalto Systems Forum 2014, Aalto University. Retrieved on August 2, 2020 from https://www.youtube.com/watch?v=0QtQqZ6Q5-0.

———. (2006). *The Fifth Discipline: The Art and Practice of the Learning Organization*. Rev. ed. New York, N.Y. London: Crown Business.

———., Bryan Smith, Nina Kruschwitz, Joe Laur, and Sara Schley, eds. (2010). *The Necessary Revolution: Working Together to Create a Sustainable World*. 1. pbk. ed. New York, NY: Broadway Books.

Snowden, David J, and Mary E Boone. (2007). "A Leader's Framework for Decision Making." *Harvard Business Review* 85 (11): 68.

Suchman, Lucy, Randall Trigg, and Jeanette Blomberg. (2002). "Working Artefacts: Ethnomethods of the Prototype." *British Journal of Sociology* 53 (2): 163–79.

Taneja, Hemant. (2019). "The Era of 'Move Fast and Break Things' Is Over." *Harvard Business Review*, January 22, 2019. Retrieved on August 2, 2020 from https://hbr.org/2019/01/the-era-of-move-fast-and-break-things-is-over.

"The Deep Dive: One Company's Secret Weapon for Innovation." (1999). ABC. Retrieved on August 2, 2020 from https://www.films.com/ecTitleDetail.aspx?TitleID=11160&r=SR.

"Tramp Bike." n.d. Wikipedia Entry. *Wikipedia*. Retrieved on August 2, 2020 from https://en.wikipedia.org/wiki/Tramp_bike.

Warfel, Todd Zaki. (2009). *Prototyping: A Practitioner's Guide*. Brooklyn, N.Y: Rosenfeld Media.