Histories and Futures of Research through Design: *From Prototypes to Connected Things*

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This article discusses how the artifact of Research through Design (RtD) is changing due to data technology. The article firstly reviews the character and role of the prototype in RtD traditions informed by practices of skillful crafting and industrial design manufacturing. It then describes the move of RtD to *data-enabled practices* to offer a conceptualization of artifacts as *connected things*, that is, decentralized objects that actively collapse the division between design participation, user interaction and the creation and distribution of products and services. By considering connected things as capable of 'making' things too, the article positions the changing character and role of the RtD artifact in relation to three key shifts in design practice: (1) the *agential shift* towards the inclusion of things as partners in design, (2) the *temporal shift* towards always available opportunities for co-creation, and (3) the *infrastructural shift* towards unstable forms of value. The article concludes with a discussion on the implications of these changes for how knowledge might be generated, critiqued and shared in future *data-enabled RtD practice*.

Keywords – Connected Things, Data Technology, Prototype, Research through Design (RtD).

Relevance to Design Practice – Through an ample collection and annotation of RtD examples, which illustrate the shifting character and role of the artifact due to data technology, this article captures the larger perspective of what working with data means in RtD and illuminates the types of questions design researchers should be asking as they move into data-enabled practices.

Citation: Giaccardi, E. (2019). Histories and futures of research through design: From prototypes to connected things. *International Journal of Design, 13*(3), 139-155.

Introduction

In 2016, the research team of the Resourceful Ageing project, an interdisciplinary collaboration funded by the Netherlands Organisation for Scientific Research (NWO) under the Research through Design (RtD) program, worked to design a sensor as small as a button, which could be attached to most objects of everyday use to act as both a co-ethnographer and a co-designer in the field. This artifact was meant to be part of a system of sensors that talk to each other and to human researchers about how older people resourcefully arrange and re-arrange groups of objects in the home to complement ageing skills. As we look back at this project (Giaccardi & Nicenboim, 2018), it was a daily struggle to collaborate and iterate on the making and deployment of this little sensor.

This struggle speaks of the types of challenges encountered by the growing community of RtD practitioners that make things that sense, log and react to data streams. The labor is not just technical (Dove, Halskov, Forlizzi, & Zimmerman, 2017; Yang, Scuito, Zimmerman, Forlizzi, & Steinfeld, 2018). Productively aligning design and research intentions in data-enabled RtD is also not just a matter of interdisciplinary collaboration (Basballe & Halskov, 2012). Data-enabled RtD requires practitioners to understand that: (a) data technologies fundamentally shift the locus of doing design towards a sustained feedback loop between design and use; (b) this feedback loop blurs former distinctions between producer and produced, that is, between the people who make and use data-enabled artifacts and the data-enabled artifacts that *make* and *use* people. This has implications for how we conceptualize the character of the designed artifact as well as the role it may play amid growing infrastructures of human and nonhuman *makers*.

This article addresses RtD practitioners who are new to making things that sense, log and react to data streams. The article also addresses RtD researchers who may have used data in their projects, but have not considered the conceptual and ethical implications for the RtD agenda when artifacts become things that actively sense, log and change in response to data streams, thus beginning to participate in design and use in ways that previous industrially produced or handcrafted objects could not.

The body of this article specifically concerns the changing character and role of the artifact in RtD due to data technology: How is the character of the artifact to be understood in data-enabled RtD practices? How is its role shifting? Other questions, such as what type of knowledge is generated, what type of research process is engaged and how knowledge is shared are certainly connected to how the artifact is understood and used in shaping processes of knowledge production and dissemination (Stappers

Received Jan. 7, 2018; **Accepted** Oct. 6, 2019; **Published** Dec. 31, 2019.

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& Giaccardi, 2017). These related questions are addressed in the discussion section of the article. It is also important to note that examples are not treated empirically. As a form of RtD critique (Bowers, 2012), they are collected and annotated to form an opinion on how the artifact and its role may be understood in RtD to establish a critical area of investigation. The examples serve as a set of representative cases into which the reader may want to dive deeper. They are by no means to be considered an exhaustive list. For all of them, adequate documentation is available. The reader is invited to refer to this documentation to better understand the specific design knowledge that has been generated and cannot be scrutinized case by case within the scope of this article.

To be clear, the framing and the contribution of this article do not concern what practical, immediately applicable knowledge can be derived from the examples in how to use data as a design material. The article also never claims that designers are new to thinking about things that never had a material form, or new to thinking about value co-creation in products and services, or that they have most familiarity with designing static, material things. The relevance of this contribution to design research is in the vocabulary offered to RtD practitioners for moving into data-enabled practices. Its relevance to design practice is in the ample collection of examples used to illuminate the key shifts produced by data technology in RtD practice and in signaling the types of questions RtD researchers should ask as they embark on data-enabled practices.

A significantly growing number of RtD projects makes use of data as a core part of the design, but we rarely step back and claim the need for an overarching perspective of prior work. Clearly, data and things have a longer history in RtD than the one accounted for in this article. The review of the literature on RtD offered by this article simply adds one more reading, one concerned with conceptual rather than methodological directions. Its aim is much more about critically capturing the larger perspective of what working with data means in RtD and less about implemented research approaches (e.g., lab, field, showroom, cf. Koskinen et al., 2011) or their historical development.

The article opens by mapping out historically dominant understandings of the character and role of the artifact as prototype in established RtD traditions. It then moves to examine and conceptualize the role of connected things in emerging data-enabled RtD practices. The article positions this change in relation to three key shifts in *doing design* produced by data technology: (1) the *agential shift* towards the inclusion of things as partners in design, (2) the *temporal shift* towards always available opportunities for co-creation, and (3) the *infrastructural shift* towards unstable forms of value. This conceptualization seeks to offer RtD researchers an understanding of how connected things can shape types of inquiry that previous industrially produced or handcrafted objects could not. The article concludes with a discussion on the implications of data-enabled RtD practices for the type of knowledge that is generated and how it is critiqued and shared.

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The Artifact as Prototype

As background to the article, this section organizes and contextualizes dominant conceptualizations of the role of the artifact in RtD. Many examples are selected here that are relevant for RtD practice. These examples were selected and annotated because of the type of historically dominant conceptualization of the role of the artifact that they represent and for being explicitly described and positioned within RtD. What design knowledge was generated specifically out of these projects and how this was generated or shared are elements intentionally not scrutinized within the scope of this article. I invite those interested in these insights to refer to the related papers.

As suggested by Redström (2017) and illustrated in Hauser et al. (2018), the relationship between how we understand designed artifacts and why we make them is important as it reveals how theoretical groundings and methodological concerns have evolved over time. Frameworks both reveal and determine the nature of the designed artifact while having a significant impact on the role an artifact can play in design-oriented research (Hauser et al. 2018). Before reviewing dominant RtD conceptualizations of the role of the artifact, this section thus briefly considers how the character of the artifact is understood in established RtD traditions. The argument put forward is that these traditions, historically informed by practices of skillful crafting and industrial design manufacturing, express an idea of the artifact as *prototype*. As it will be further illustrated in the section about data-enabled RtD practices, this idea is challenged by data technologies and how data-enabled artifacts come to exist in a connected world.

Design as Stabilizing Process

No matter whether we use artifacts to demonstrate possibilities or provoke and speculate on alternative futures, as a vehicle for critique or for developing theories, and independent of whether they are props or fully functional devices, artifacts play an essential role in RtD. They are the primary means to ask particular research questions. Made for research purposes and often referred to as *research artifacts* (Zimmerman, Forlizzi, & Evenson, 2007), they are not to be confused with products intended for the consumer market. Their role "as vehicles for research about, for and through design" is manifold (Wensveen & Matthews, 2014, p. 262).

Yet, I would argue that until recently much of RtD making (including that of digital artifacts) has been significantly influenced by the long-established practices of skillful crafting and industrial design manufacturing, implicitly reflecting an understanding of the artifact as a single product. This is an artifact that although not final is equally conceived as a material *embodiment* (Stolterman & Wiberg, 2010) or *manifestation* (Lim, Stolterman, & Tenenberg, 2008) of the ideas, skills and knowledge of the

designer and which can be experienced by others. Often referred to as *prototype* (Stappers, Sleeswijk Visser, & Keller, 2014), it is a sketch, a mock-up or polished material outcome confronting the world of ideas and skills of the designer with the world-out-there *before a final artifact exists* (Bucheneau & Fulton Suri, 2000).

To clarify, I am not trying to argue here that RtD *tout court* converges on a single product stance. We know there are other historical threads mixed into the heterogeneous RtD community that present ideas about design beyond the product, 'thinging' and infrastructuring, and I attend to these conceptually in the section about connected things. However, as argued by Gunn and Donovan (2012), the role of the prototype in established design practices is often to support people to imagine, discuss and shape future states at project time. In this sense, doing design is a kind of *stabilizing process* through which future practices are imagined and experimented at project time, then realized. In RtD approaches informed by participatory processes of co-reflection and co-design, this stabilizing character of the artifact is expressed in the way in which the prototype helps achieve a sort of consensus among designers and *non-designers* (Sanders & Stappers, 2014). The same orientation is also reflected by the way that ethnographic methods have been traditionally adopted and domesticated in RtD practice. Motivated by the need for the artifact to be deployable in the field for an extended duration and to be *lived-with* and experienced over time in the context of everyday life, Odom et al. (2016) propose that the artifact of RtD should be considered as a *research product*. This proposition emphasizes the *actuality* of the designed artifact and suggests that the engagement that people have with it should be "predicated on *what it is* as opposed to what it *might become*" (p. 2550).

This is not to dispute the intrinsically transformative character of the act of design, but the orientation of the process here is somehow one of resolution. Although provisional, unfinished and not for sale, the artifact of RtD traditions as grounded in long-established practices of skillful crafting and industrial design manufacturing is an object around which behaviors and values are meant to precipitate and converge, if then to diverge again at use time. The following examples illustrate how this understanding has significantly informed conceptualizations of the role that the artifact can play in RtD. These conceptualizations differ with respect to the capacity in which the artifact is used to either evaluate design decisions or generate directions for research. They are different with respect to the actuality and material qualities of the designed artifact. They are different with respect to the type of state that is imagined and manifested, which can be fictional or utterly provocative. However, they are similar with respect to how they have been historically informed by traditional crafting and industrial design to think of the artifact as actual and realized.

Using Prototypes for Evaluating Design Outcomes

One way of using prototypes is to support a process of reflection on the design activity and its outcome, what worked and what did not work. When serving this function, artifacts are used primarily in their evaluative capacity. In Keller's (2005) *Cabinet* study (Figure 1) the sequence of prototypes aims to support activities of collecting and organizing images for the purpose of design inspiration. Much of the learning in this project occurred during the making of the prototypes and through the explanations and discussions with lab visitors at informal presentations, rather than through formal experiments.

Using Prototypes for Empirically Testing Hypotheses

In some cases, prototypes are designed to test initial hypothesis and as a vehicle for theory building. Here, artifacts are used as instruments for data collection in experimental or quasi-experimental empirical evaluations. Artifacts like Wensveen's (2005) *Alarm Clock* (Figure 2), designed and produced to map patterns of movements of participants in the lab onto different emotional moods, have as their ultimate goal to identify and generalize theoretical design principles, in this case concerning how to design for emotion in tangible interaction.

Figure 1. *Cabinet*: Testing how to collect and organize images for design inspiration (Keller, 2005).

Using Prototypes for Supporting Material Exploration

Prototypes can also be capitalized as demonstrators to give direction to research and help it unfold, often through material exploration (Löwgren, 2015) and in ways that open up not fully anticipated design spaces (Brandt, Redström, Eriksen, & Binder, 2011; Mazé & Redström, 2008).

In the *Switch!* project, artifacts embed and are the primary means to ask particular research questions. These are a series of experiments on how designed, interactive artifacts can promote awareness of energy use in everyday life. Figure 3 provides images from the material development and household study of *Telltale*, a piece of furniture that collects traces of energy habits (Bergström et al., 2013).

Similarly, the series of early designs produced by Holly Robbins as part of her PhD research (Figure 4) are a means to form and ask research questions, in this case about how traces of use can help people construct a more transparent and possibly ethical relationship with technology (Robbins et al., 2016).

Prototypes can help designers explore design spaces simply by filtering and manifesting particular regions within an imagined or possible design space (Lim, Stolterman, & Tenenberg, 2008). For example, Figure 5 is a collection of material samples by Karianne Rygh produced to explore and express the solution space of Canon Océ 2.5D printing technology. These prints stand in the world by themselves as the manifestation of a particular design space enabled by a particular technology.

Using Prototypes for Exploring Areas of Concern

Prototypes can be explicitly used without any attempt to produce generalizable knowledge. They can be collected and annotated to establish interesting areas for exploration and judgment, whether aesthetic, social or political. In this, they can be relevant to both designers and audiences in multiple ways.

The *Drift Table* (Figure 6) is a coffee table with a small viewport showing a slowly changing aerial view of the British landscape, an open study of the impact and opportunities of digital technologies for the domestic environment. The purpose of the artifact is playful and open-ended, an invitation to participants in the study to "be surprised, learn what can be learned" and "a mechanism for developing new values and goals, for learning new things, and for achieving new understandings" (Gaver et al., 2004, p. 885)

Similarly, the *Indoor Weather Station* (Figure 7) presents small domestic appliances intended to draw attention to the microclimate of the home, exploring a less didactic approach to environmental sensing. They are artifacts with a definite functionality, state of the art technology, but explicitly not grounded in user needs, functional purpose, or intended benefits (Gaver et al., 2013).

Using Prototypes for Provoking Alternatives

Prototypes can also be used to intentionally provoke and speculate on alternatives. Provocations can be sought to disrupt or transgress social and cultural norms and thus stimulate discussion and debate (Bardzell, Gross, Wain, Toombs, & Bardzell, 2011), or to reflect on

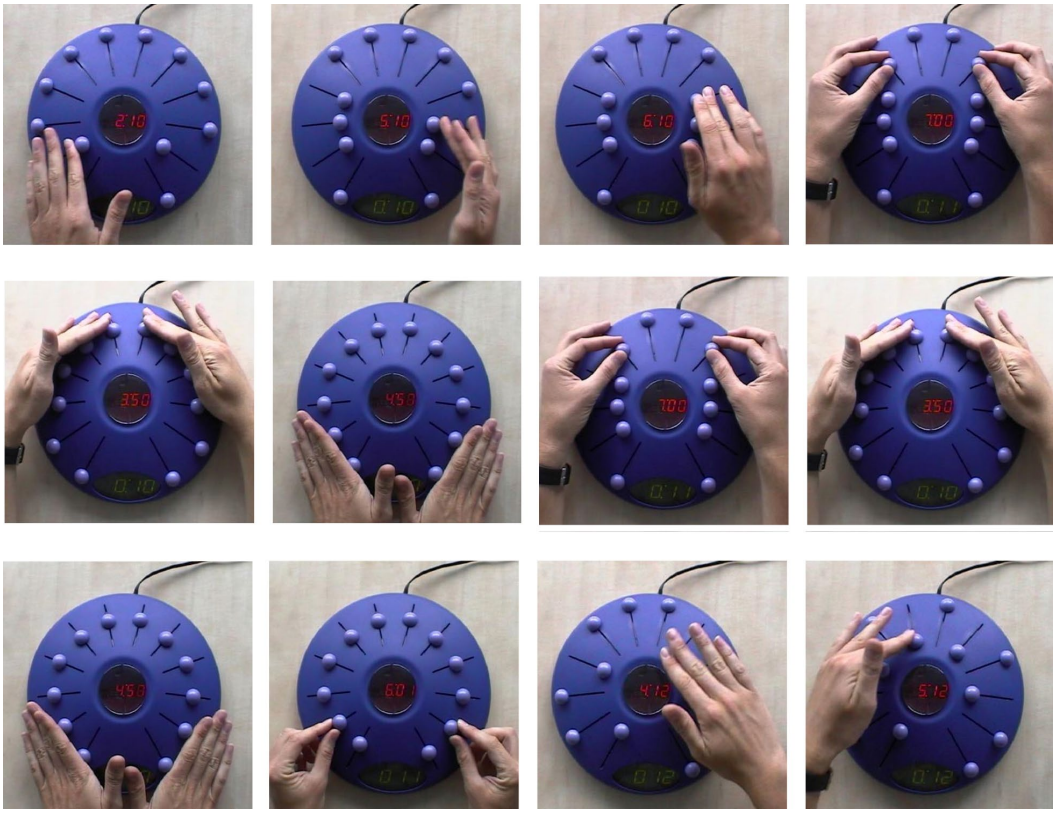

Figure 2. *Alarm Clock*: Designing for affective interaction (Wensveen, 2005)**.**

Figure 3. *Switch!*: Experimenting how interactive artifacts can promote awareness of energy use in everyday life. © 2013 Interactive Institute 'Switch! Telltale' project team Jenny Bergström, Brendon Clark, Alberto Frigo, Ramia Mazé, Johan Redström, and Anna Vallgårda.

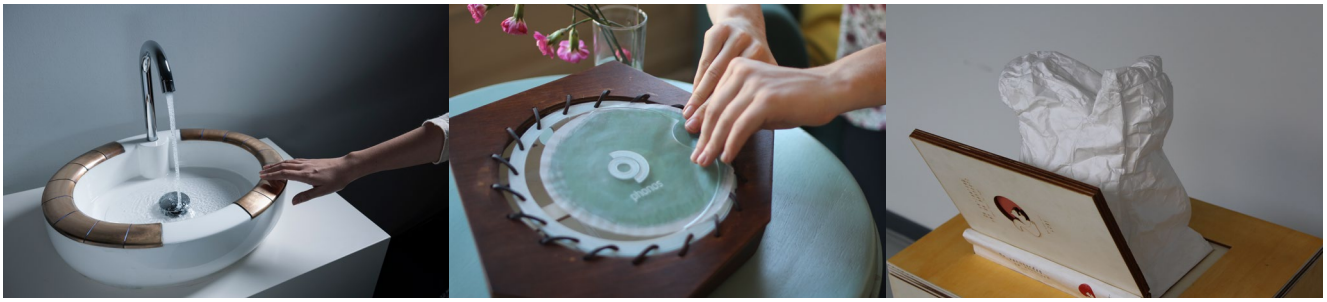

Figure 4. *Mizu* (a), *Phonos* (b), *Animals' Tales (*c): Experimenting with traces to design for ethical relationships with technology (Robbins, Giaccardi, & Karana, 2016).

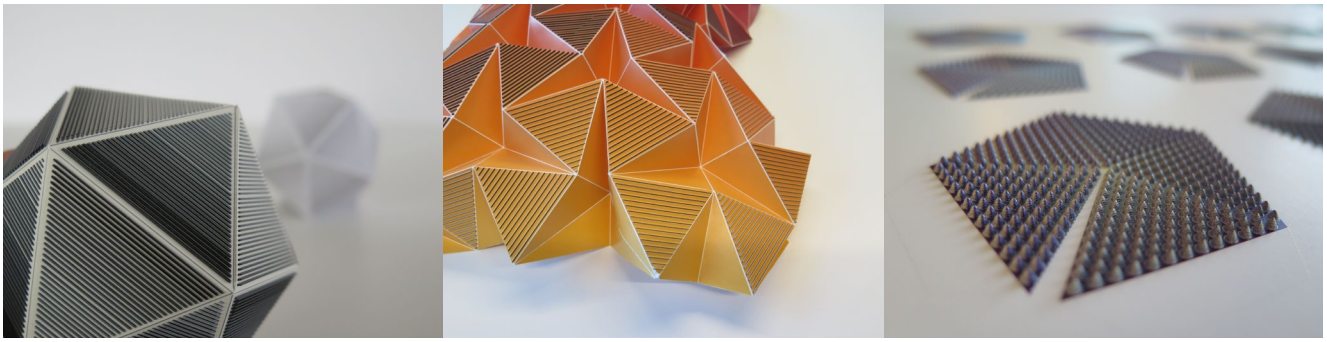

Figure 5. *Canon Océ 2.5D printing*: Collection of material samples © Karianne Rygh.

Figure 6. *Drift Table*: Designing for ludic engagement © Interaction Research Studio.

Figure 7. *Indoor Weather Station*: Investigating a ludic approach to environmental HCI © Interaction Research Studio.

our own world and to generate alternative possibilities for the future (Wakkary et al., 2015). In this case, the artifact is not a demonstration of what is possible now; it opens up an imaginative space.

The *Inaccessible Digital Camera* (Figure 8), where the SD card with stored images can be accessed by sawing and breaking apart the basswood enclosure, is a *counterfunctional* artifact open to multiple interpretations and meanings (Pierce & Paulos, 2015).

Similarly, the *Table-Non-Table* (Figure 9) is a slowly moving stack of paper supported by a motorized aluminum chassis. The *Table-Non-Table* is designed to operate entirely unaware of its owner's presence or actions and provoke a range of speculations as participants attempt to make sense of its purpose and place within their homes (Wakkary, Desjardins, & Hauser, 2015).

The same orientation is expressed by the *Significant Screwdriver* (Figure 10). The screwdriver would record and visualize data about how it is used in the home and who uses it. It has the intent of transgressing social norms regarding the gendered division of labour in the domestic sphere to yield insights toward a better quality of domestic life (Bardzell et al., 2011).

Using Artifacts for Prototyping Solution Spaces

In some cases, the meaning of the material artifact as a research tool lies not in the product per se but in the way it enables the simulation and prototyping of experiences and practices. Its role is not to open up an imaginative space, but rather to improvise and experiment with a solution space in the here and now.

Figure 8. *Inaccessible Digital Camera*: Opening counterfunctional artifacts to multiple interpretations (Pierce & Paulos, 2015).

Figure 9. *Table-Non-Table*: Intersecting with unaware objects in the home (Odom & Wakkary, 2015).

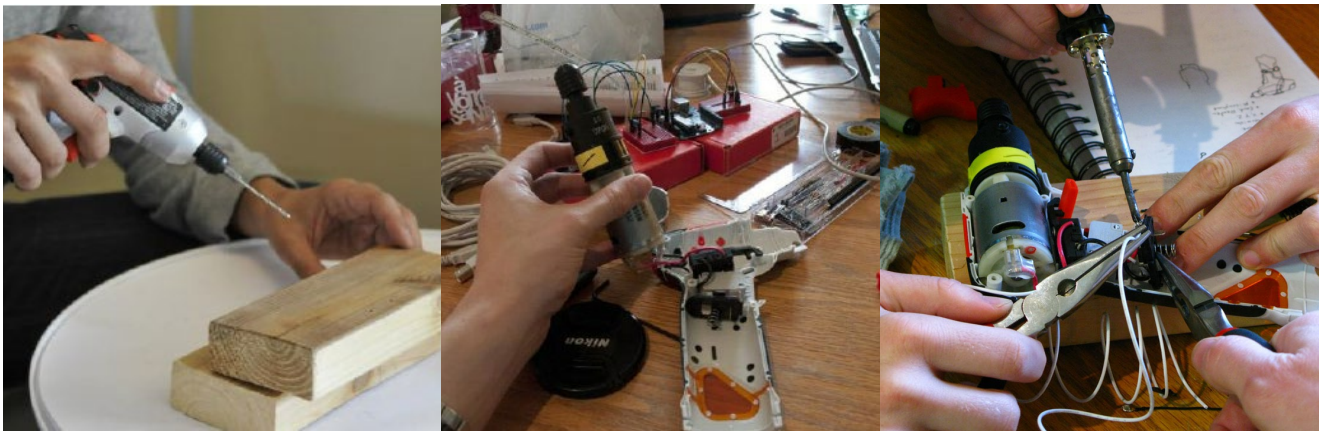

Figure 10. *The Significant Screwdriver*: Transgressing social norms in the domestic sphere (Bardzell et al., 2011).

In *Embodied Futures* (Figure 11), props are used to simulate and experience reduced freedom of movement, with the intent to support empathic engagement with how a disabled person might feel (Wilde, 2011). Here the artifact is not what is being made, just a mere choice of convenience aimed to bring about or sustain a specific experience.

Similarly, the rough prototype of *Splash* (Figure 12) is used as a prop by participants to perform and design more sustainable forms of bathing that require lower amounts of water, similar to splashing (Kuijer et al., 2013).

From Prototype to Connected Thing

This section provides a theoretical lens for when RtD moves from single products to *connected things*. The argument here is that connected things are data-enabled artifacts that hold both perception and possible agency: they sense, log and react to data streams and can autonomously make judgments and perform connections to other products and services. Connected things participate in both design and use in ways that previous handcrafted and industrially produced objects could not. The participation and performance of such things in potentially unpredictable arrangements and collaborations of human and nonhuman resources profoundly challenge the stabilizing character of the artifact that has been inherited from previous practices of skilful crafting and industrial design manufacturing. Data-enabled artifacts open uncharted territories for how RtD practitioners might engage with connected things, urging them to ask new types of questions. To elaborate on these questions, I use examples from the data-enabled practice of colleagues within the growing RtD community as well as my own. As with established RtD traditions, examples are not treated empirically. They are collected and annotated with the aim to surface critical areas of investigation for the role that connected things may play in future RtD practice and to illuminate the relevant questions.

Design As Probabilistic Outcome

Present data-enabled RtD practices emphasize the importance of using data as a design material for the purpose of exploring and co-creating with users new design directions (Bogers, Frens, van Kollenburg, Deckers, & Hummels, 2016; Zimmerman et al., 2011). Emphasis is often placed on the need to gain deeper insights into user experience by integrating quantitative and qualitative methods for long periods of time and engaging with users continuously and remotely (van Kollenburg et al., 2018). Similarly, several RtD practitioners have begun to engage with data and intelligence as a design material for purposes such as tracing and materializing industrial infrastructures and making them available for design and participation (Davoli & Redström, 2014), repurposing automation and monitoring technologies in alternative agricultural practices (DiSalvo & Jenkins, 2015), drawing attention to the socio-political topology of the lived environment that is experienced through data (Boucher & Gaver, 2017) or speculatively addressing concerns with digital objects (Pierce & DiSalvo, 2017) and data-enabled life (Elsden, Durrant, Chatting, Green, & Kirk, 2017). There is growing awareness that attending to the objects of RtD requires a new conceptual framing (Jenkins et al., 2016). My argument is that developing a useful conceptual framing for data-enabled RtD practice requires moving past ideas of the artifact as prototype to reconceptualize its role in RtD processes of knowledge production in the light of a changed design paradigm.

Figure 11. *Embodied Futures*: Supporting empathic engagement with disability (Wilde, 2011).

Figure 12. *Splash*: Performing more sustainable forms of bathing (Kuijer, de Jong, & van Eijk, 2013).

Connected things are different from single products. As argued in design research after Heidegger (Ehn, 2008; Tonkinwise, 2005), a thing is not the artifact in its actuality but in its *potential*. In simple terms, we could think of a thing as the designed artifact, plus the people or other artifacts that relate to it and how they relate to it. In design, we often think of this relationship as one of use, though of course use is a simplification of the more entangled relation we have with things and that things have with us and with other things. We don't just drink from a cup but relate to it in multiple ways: we may *misuse* it as a penholder or we may even grab it to catch a fly, improvising with it in combination with other things such as the kitchen table. Understanding how to design a cup as a *product* or a *thing* entails very different aesthetic and ethical considerations, for example, with respect to its dimensions of openness (Giaccardi & Nicenboim, 2018).

Redström and Wiltse (2018) argue that with digital objects, the relations and assemblages that *make* things in everyday life become unstable. A thing such as a smartphone can be used in a vast number of ways. It also becomes something different in terms of *what it is, what it does and why*, depending on how the user intentionally frames it as an object. My smartphone is not the same as yours. It uses different apps, different data, for different purposes, it means something different and it does it differently.

I would argue that the trouble is even greater. Today autonomous vehicles, assistants such as Alexa, Google Home and Cortana, drones that deliver purchases within minutes of placing an order, Ethereum tokens and smart contracts are things that increasingly do business with humans and with each other (Iqbal, 2019). As things become enabled through the exchange of data to make judgments and perform actions that create new connections and shape new relations to both people and other things, we must acknowledge that things not only *change* as earlier suggested; things *make* things too. Unstable, probabilistic and agentive, the artifact becomes part of a *decentralized making process* through which future practices are endlessly experimented and reconfigured in the present. Such a decentralized process is increasingly blurring distinctions between design and use, subject and object, producer and produced (Porter & Happelmann, 2014; Neese, 2015), collapsing the traditional division between participation (before design), interaction (in use) and the creation and distribution of products and services (after design). This problematizes how *things making things* can and should take part in design work alongside both professional designers and everyday designers. It is not just about making, evaluating and using prototypes; it is about finding new designerly ways to engage with and bump against a different type of thing.

Considering connected things as being capable of making things alongside people challenges the idea of humans and artifacts as independent from each other. Theoretically, the argument aligns with design work variously concerned with the entanglement and reciprocity of nonhuman actions and human purposes (Devendorf & Ryokai, 2015; Forlizzi & DiSalvo, 2006; Leahu & Sengers, 2015; Taylor, 2017) and analyses of how technological innovation triggers change in the way agency is configured in social practice between humans and nonhumans (Kuijer & Giaccardi, 2018). For design practice, conceptualizing connected things as capable of making things next to humans shifts the locus of doing design towards a fundamentally *recursive relation* between design and use, producer and produced, a relation that needs to ethically balance and integrate capabilities and doings uniquely human (e.g., improvisation) and uniquely artificial (e.g., foresight).

Through this theoretical lens, I describe how the feedback loops that data technology introduces in doing design fundamentally change the character of the artifact of RtD and open up new roles for the artifact in designerly processes of knowledge production. I focus on three key shifts: (1) the *agential shift* towards things as partners in design, (2) the *temporal shift* towards always-available opportunities for co-creation, and (3) the *infrastructural shift* towards unstable forms of value.

Agential Shift: Rehearsing Design Partnerships

Differently from a prototype manifesting perspectives generated by humans only, connected things take part in design too. In this sense, they may act as partners with uniquely artificial abilities and perspectives (Giaccardi, 2020). The questions here concern:

- How does partnering with connected things in RtD practice challenge traditional modes of doing design work?
- How can RtD promote alignments between humans and nonhumans that offer new designerly ways of understanding what we know and what we do?

In the *Resourceful Ageing* project, we experimented with how to include things as co-ethnographers and co-designers in the field. Our concern was how to use Internet of Things technology to turn everyday use into a potential design situation (Giaccardi & Nicenboim, 2018). Our first artifact *Cúes* was designed to act as a nonhuman ethnographer with artificial sensing capabilities. As such, it was meant to help human ethnographers observe how everyday objects were used in the homes of the elderly in ways that might escape human observation or sense of relevance. Additionally, *Cúes* was envisioned to act as a co-designer on the basis of the patterns of use (or resourcefulness, here) it would have been able to observe. As such, it was meant to make recommendations to older people on what strategies of resourcefulness should be reinforced and carried out. This initial design orientation in the project was still informed by understanding design as a kind of stabilizing process, where the *predictability* of patterns is used to enforce compliance to scripts made by the designer at project time. After several design iterations and machine learning experimentation, we came to understand that the true value of the design partnership with connected things resided instead in how they could help us capitalize on the outcome of machine learning as probabilistic—in other words, to improvise rather than prescribe.

Eventually, *Cúes* evolved into *Connected Resources* (Figure 13), a family of sensors and actuators that older people can improvise with and combine in a variety of ways to add digital capabilities to objects of everyday use and complement their ageing skills (e.g., hacking one's entry door and preferred mug with a combination of Messaging Bell (sound sensor) and

Figure 13. *Connected Resources*: Improvising practices of resourcefulness in elderly homes.
Photo of tablet application by Andreas D'Hollandere; other images by Masako Kitazaki (2018).

Lightening Clip (light actuator) in order to 'see' when someone is at the door). *Connected Resources* act as co-ethnographers by learning from how they are combined and deployed; in doing so, they also act as co-designers by encouraging older people to learn from each other, try different combinations and develop shared norms about what might be considered 'normal' and socially acceptable strategies. While both *Cúes* and *Connected Resources* participated in the project as co-ethnographers and co-designers, the role played by *Connected Resources* as a partner is quite different in terms of the type of knowledge and objects of design that were generated. *Connected Resources* are not at work to help the designer figure out what to design or what better service to provide. Powered by machine learning, *Connected Resources* are at work to empower older people to negotiate their desire level of independence *in* and *through* use. In their role as partners, *Connected Resources* turn the probabilistic outcomes of machine learning (i.e., interpretations about older people's behavior) into material and social affordances that older people can use to configure resourceful arrangements of sensors and actuators within the home and, more importantly, to negotiate shared social norms about what is a purposeful and vital way to age.

In the *Stimulating Creative Dialogues Between Humans & Things* project (Amram, 2016), *Sensers* are homemade sensors designed to act as co-ethnographers to support makers in the do-it-yourself process. In this project, domestic artifacts are hacked and transformed into connected things by makers themselves, with the goal to open up their design space to new sources of inspiration. *Sensers* observe and make suggestions through streams of data visualization that feed in the design process of the makers, inspiring them to unanticipated home improvements. For example, different

types of *Sensers* were used to hack the shared kitchen of one of the participants (Figure 14). The insights generated by the correlation of sensor data revealed that smells in the kitchen originated because the window was often forgotten due to the height of the latch. This was the case because the latch was often either left closed during cooking (keeping smells in the house) or left open after dinner (causing drops in temperature). However, it was soon clear that it was hard for makers to engage with things as partners in a type of ethnographic inquiry when this was unfamiliar to them. After experimentation and several iterations, *Sensers* evolved into *MakeDo*, a speculative design concept promoting a decentralized design partnership with things through data sharing (Figure 21). *MakeDo* is a platform for DIY recipes where data collected from things about their use becomes an integral part of the making process. Conventionally, DIY recipes are created, published online, downloaded, made into a physical artifact and eventually used. *MakeDo* closes this loop by feeding use data back into the DIY recipe to encourage social creativity.

These cases exemplify how connected things can be conceptualized and designed to act as partners in a RtD process. *Cúes* played an important role as co-ethnographer, providing access to nonhuman perspectives on older people's use practices which had fallen outside of our human sense of relevance and which helped us to problematize the design space rather than locking us into ideas of predictability and normativity (Giaccardi & Nicenboim, 2018). As co-designers, *Connected Resources* and *MakeDo* played an even more important role, enabling design-in-use and social creativity.

By enabling access to trajectories unattainable to human observation and making suggestions for us and with us**,** even contesting our worldview, for example, about what it means to age independently or what is the purpose of making**,** *Connected Resources* and *MakeDo* are more than just collaborators in achieving human originating purposes (Grudin, 2017). They contribute a different perspective and unique insights on human practices that may be used to enhance, complicate and even challenge those of humans (Giaccardi, Speed, Cila, & Caldwell, 2016).

This type of partnership requires engagement. It assumes the need to spend time together and work together, humans and nonhumans alike, towards new ways of understanding what we know and what we do. New understandings are inherently transformative. When it comes to connected things, they allow for reframing and reconfiguring social and material relations *in* and *through* use. In the *Resourceful Ageing* project, for example, the way we engaged with things over two years supported a RtD practice that challenged the unethical technology push of mainstream gerontechnology, allowing us to experiment with how older people can be empowered to reframe and reconfigure Internet of Things technology, and thus notions of care, according to always-changing personal circumstances and social norms about what is a vital and acceptable way to age (Giaccardi, Kuijer, & Neven, 2016).

Learning how to engage with things as partners may help problematize assumptions and biases originating from humans. It may sustain data-enabled RtD practices that critically challenge mainstream understandings of what is possible and appropriate to research and design with data technology.

Temporal Shift: Harnessing Sustained Co-creation

Connected things facilitate a design process where conventional, clearly identifiable RtD iterations are superseded by always-available opportunities for conversation and co-creation. Relevant questions are:

- How can a sustained, data-enabled process of conversation reconfigure modes of participation and co-creation in RtD practice?
- How do we dream of responsible and desirable futures together with algorithms and artificial forms of intelligence?

In *Conversations with my washing machine*, an in-the-wild study of demand shifting with self-generated energy, Bourgeois and colleagues (2014) used a tablet in combination with a mobile app as a hack to domestic washing machines (Figure 15). The goal was to facilitate participatory data analysis of self-generated energy use. During these participatory sessions, the sustained conversation of participants with their washing machine produces useful insights to feed the design process of an energy-aware washing machine.

In a similar participatory fashion, *LED-Sphere* visualizes open data to support the co-creation of public services in the Rotterdam Open Data project (Mulder, 2015). *LED-Sphere* highlights the density of trees in the city by linking trees to their GPS position. Taking the sphere along during a walk in the city, the LEDs' intensity increases when the environment becomes greener. *LED-sphere* visualizes invisible data that fosters and sustains people's imagination and empowerment in discussing opportunities for the co-creation of public services (Figure 16).

In these projects, as observed also in the projects *Resourceful Ageing* and *Stimulating Creative Dialogues*, live access to data accelerate and compress iteration into more fluid forms of design-in-use.

As previously discussed, in user-centered and participatory design approaches, the role of a prototype is often to support a kind of stabilizing process through which future practice(s) are imagined and realized (Gunn & Donovan, 2012). In these approaches, participation has clear temporal boundaries and is usually confined at project time. Instead, the growing infrastructural collaboration of human and non-human actors that is enabled by data technology challenges designers to support ways of understanding and designing that take place after, with and beyond the design work at project time (Binder et al., 2011; Ehn, 2008; Redström, 2012). Rather than focusing on involving users in the design process by means of prototypes, living and partnering with connected things challenge us to see every situation of use as a potential design situation.

A shift from the *projecting* of design activities to their *infrastructuring* has been advocated in design for a long time (Ascott, 1994; Ehn, 2008; Giaccardi, 2003). What is new is that we are not looking anymore at how humans can align non-human resources in a design project to move the object of design forward (Björgvinsson, Ehn, & Hillgren, 2012). The always-available opportunities for conversation among people and things enabled by data technology confront designers with a greater autonomy of

Figure 14. *Sensers*: Stimulating creative dialogues between humans and things in makers' homes (Amram, 2016).

Figure 15. *Conversations With My Washing Machine*: Sustaining participatory data analysis of self-generated energy use (Bourgeois et al., 2014).

Figure 16. *LED-Sphere*: Sustaining the co-creation of public services with open data (Mulder, 2015).

the artifact and with potential misalignments. Experimenting with how algorithms and artificial forms of intelligence may contribute to harness the sustained co-creation of future ways of living will require a nuanced consideration of the contextual significance and situated value of the data used.

Infrastructural Shift: Assembling Forms of Value

Connected things can generate value by forming networks, communicating and performing actions and judgments in a highly dynamic way and with different degrees of autonomy. The shifts towards a greater autonomy of the artifact (agential shift) and towards decentralized forms of co-creation (temporal shift) means that value is now generated directly within the process, rather than as a result of an a posteriori assessment of the validity or projected desirability of the design intervention. What we should ask then is:

- How do we critique the fluid experiences and forms of value generated by data-enabled RtD practice?
- How differently should we look at the outcomes versus the process from which value has emerged?

The exploration of this shift was at the core of the *Things2Things* project (Giaccardi, Speed, & Netten, 2016). The outcome of these explorations are *KASH Cups* and *Morse Things*. *KASH Cups* (Speed, 2016) is a limited edition of RFID augmented ceramic coffee cups that operate as a pop-up digital currency (Figure 17). *KASH Cups* mobilize data about how the cup is used to explore how economic and social value are integrated in use. Use value, economic value and social value are often disguised in the habitual processes of using money as a representation of value. The *KASH* cup materializes and reconfigures these values by displaying the credit status of each cup and asking people to add to such value (economic) by spending time to meet and talk to each other (social value). Credit is then spent at the point of purchase (use value), where the barista swaps the credit for a cup of coffee.

Similarly, *Morse Things* (Wakkary et al., 2017) are ceramic bowls that communicate with each other and their human partners in Morse code (Figure 18). Long-term studies have indicated that the bowls' unintelligible communication is valued as an unexpected opportunity for everyday design which participants construct through their daily lives with such artifacts. In both

cases, artifacts present very tangible and purposely designed physical qualities. Yet, their materiality is quite fluid and complex. Borrowing from an aesthetic analysis of contemporary digital objects as *fluid assemblages* (Redström & Wiltse, 2018), we can understand this materiality as a continuous, developing flow of relations and interactions that is made possible by the exchange of data and that changes the value of the experience as it unfolds.

The agentive capability of connected things to form networks, communicate and carry out performances and judgments next to people with varying degrees of autonomy further problematizes what we understand as the prototype in RtD practice. Conceived as the preliminary version of a technical object or possible future, prototyping usually concerns envisioning and rehearsing use before use (Björgvinsson et al., 2012). But in today's space of flows, "new ways to leverage the value of what—and whom—we know are bound to emerge that nobody has thought of yet" (Thackara, 2005, p. 165). As earlier envisioned by Thackara, designing a space of flows needs to be continuous and it needs to focus on *how things work* rather than on *what they look like*. This challenge posed to design, however, entails not only a change in the relationship "between the people who make things and the people who use them" (p. 223). It involves a fundamental change in the relationship between the *people who make things* and the *things that make people*. With things exchanging data and providing feedback as to how a design may *generate and sustain worth* (Speed & Maxwell, 2015), RtD practitioners have now the opportunity to re-arrange and re-configure existing flows into provisional things that, like *KASH Cups, Morse Things* and also *Connected Resources*, allow for experiences and forms of value that are different for different people under different circumstances and intentionalities.

Implications for Data-enabled RtD Practice

Conceptualizing connected things as *things making things* and offering a lens to look at the new roles such things can play in RtD signals a direction for new types of inquiry. It also calls for beginning to unpack some of the implications that such RtD inquiries may have for the type of knowledge that is generated and how it is critiqued and shared.

In this final discussion, I suggest that understanding how knowledge is to be critiqued and shared in data-enabled RtD practices seems to require new audiences, channels and formats. We should revisit the consolidated traditions of dissemination that RtD depends on, such as individual academic publications and isolated exhibitions of design artifacts to move towards more collaborative forms of value generation (Robbins & Giaccardi, 2019). In addition to new forms of dissemination and critique, data-enabled RtD practices raise ethical considerations for how knowledge is shared, used and re-used in the context of an expanded and decentralized design process. In this final discussion, I signal an additional set of questions that RtD researchers should ask as they embark on data-enabled practices.

What Knowledge Is Critiqued and How?

What kind of knowledge is the knowledge generated through data-enabled RtD practices? Even more importantly, how it is critiqued? Is relevant to design only the artifactual knowledge that is produced in the physical making, ethnographic deployment and multiple framings of a connected product? Or should we consider

Figure 17. *KASH Cups*: Configuring constellations of value (Speed, 2016).

Figure 18. *Morse Things*: Creating unexpected opportunities for everyday design (Wakkary et al., 2017).

relevant artifactual knowledge also the decisions concerning, for example, what data has been collected, according to what metrics it has been filtered, what machine learning model has been used to make sense of it and so on?

Perhaps this is not the most interesting question. As long as the knowledge is useful to someone, then we can argue that it is valuable. More pressing is the question of how we can critique connected things. How can we critique, for example, the assumptions and biases that are encoded in the algorithm? When we critique such assumptions and design decisions, whose intentions are we concerned with? Are we concerned with the experience of the user only, or are we to critique whether and how the artifact we made connects to other platforms and services and how it might serve other purposes and intentionalities?

Unpacking the agency and socio-materiality of connected things and the role these play in a particular RtD project requires forms of critique more than forms of knowledge dissemination.

Given the potential impact of data-enabled RtD practices in everyday life, forms of public critique may be preferable. These forms of critique should be less of an internal affair among academics or professional designers and call instead for a broader range of expertise and problem ownership to be brought to bear on the construction of knowledge and the relevancy of the work. Settings where the data-enabled RtD process (with its intangible material elements, performances, and flows) is at the heart of the representation and discussion should be preferred to settings where the artifact is framed in isolation, primarily in its physicality. For example, *Why does my refrigerator know my birthday?* is an exhibition curated by the Just Things Foundation for the Dutch Design Week 2016. It combines the physicality of speculative prototypes with the visualization of their hidden elements (Figure 19). *Thingformation* was commissioned for this exhibition. Similar to clothing wash labels, *Thingformation* uses simple symbols to convey some of the complexities of a connected thing that are not immediately apparent such as: type of encryption used, number of companies affiliated with it, expiration date, what body of laws regarding data protection is the product being held accountable to, and a grade evaluation of the brand's trustworthiness (Robbins & Giaccardi, 2019). Other speculative concepts and prototypes in the *Why does my refrigerator know my birthday?* exhibition offer similar affordances towards a display format that makes the intricacies of connected things more accessible to public critique.

Who Is Sharing What with Whom, or with What?

Another shift in the production of knowledge within data-enabled RtD practices concerns the parties who are involved in sharing, using and re-using the knowledge produced. Internally to the team, a data-enabled RtD project like *Resourceful Ageing* may require knowledge to be generated by and shared between humans and also autonomously among things (Figure 20). This new condition challenges RtD practitioners to consider how to enable data exchange and knowledge production in ways that are nuanced and ethically responsible. Who or what can participate and how? How do we build trust in non-human partners? How is the sharing of insights among things accounted for, both at the onset of a data-enabled project and in relation to how knowledge will be used?

Externally to the project team, there is also a question of privacy that infringes on the development of collective platforms for data sharing. In the speculation of Amram (2016), furniture is designed and assembled using knots with sensing capabilities. In the creative conversation between humans and non-humans that is enabled through the sensors embedded in the knots—that is, in the conversation between makers and the sensing, assembled furniture the makers create and live with—insights about the suitability or desirability of the assembled furniture within a certain context can be continuously generated and shared.

Using the *MakeDo* data sharing platform (Figure 21), a maker could create plugins and compare several do-it-yourself recipes of stools on the basis of requirements including the measured stability or the inferred amount of jokes deduced from the shared data. Research with makers (Amram, 2016) has suggested that data sharing platforms where things partner with a broader community of practitioners could overcome the fixations that often come with the use of data technologies in the design process (e.g., fixations with the framing of the problem to be solved, or fixations for how automation can solve the problem). The

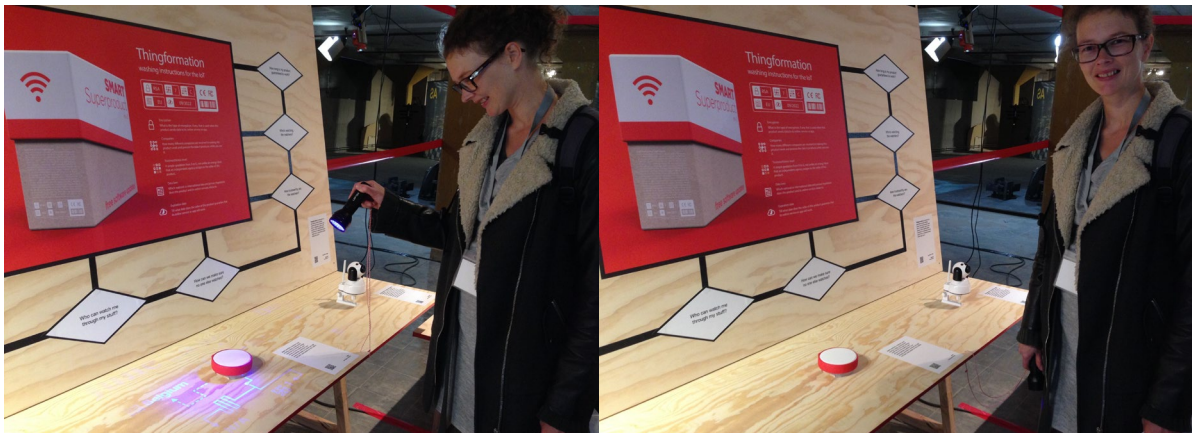

Figure 19. *Thingformation in the Why does my refrigerator know my birthday?* exhibition at DDW 2016 as a form of public critique. Photo by the author.

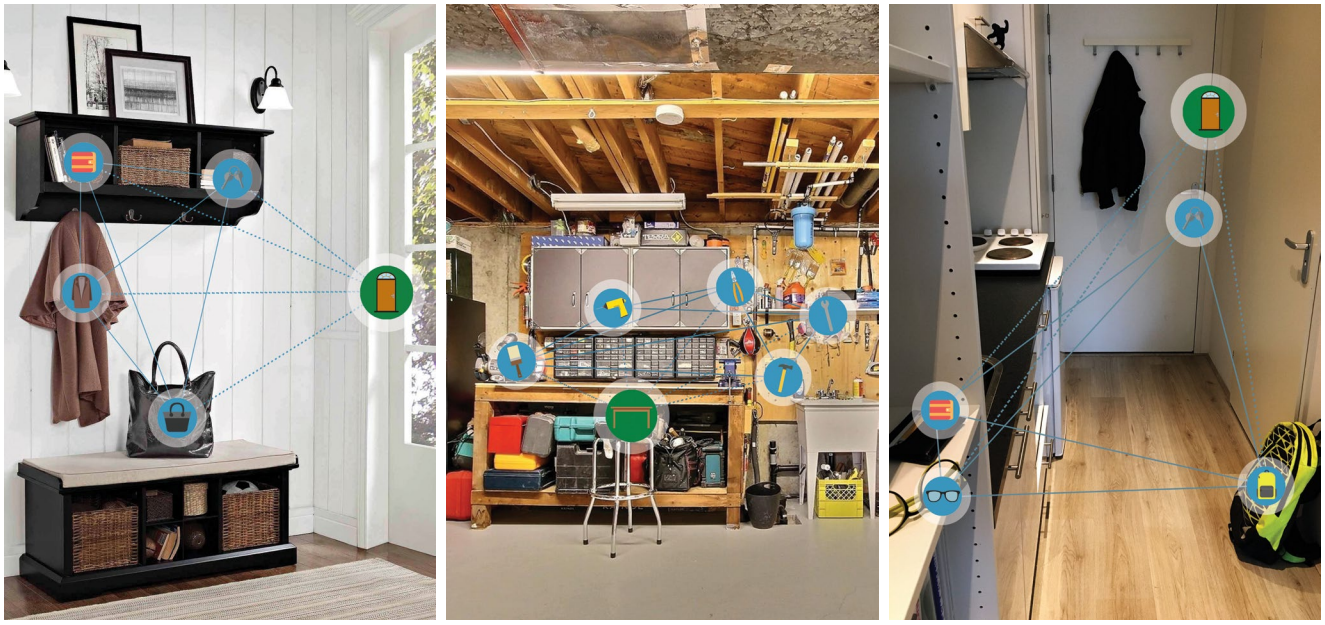

Figure 20. *Cúes*: Autonomous sharing of insights among connected things (Fusaro, 2016).

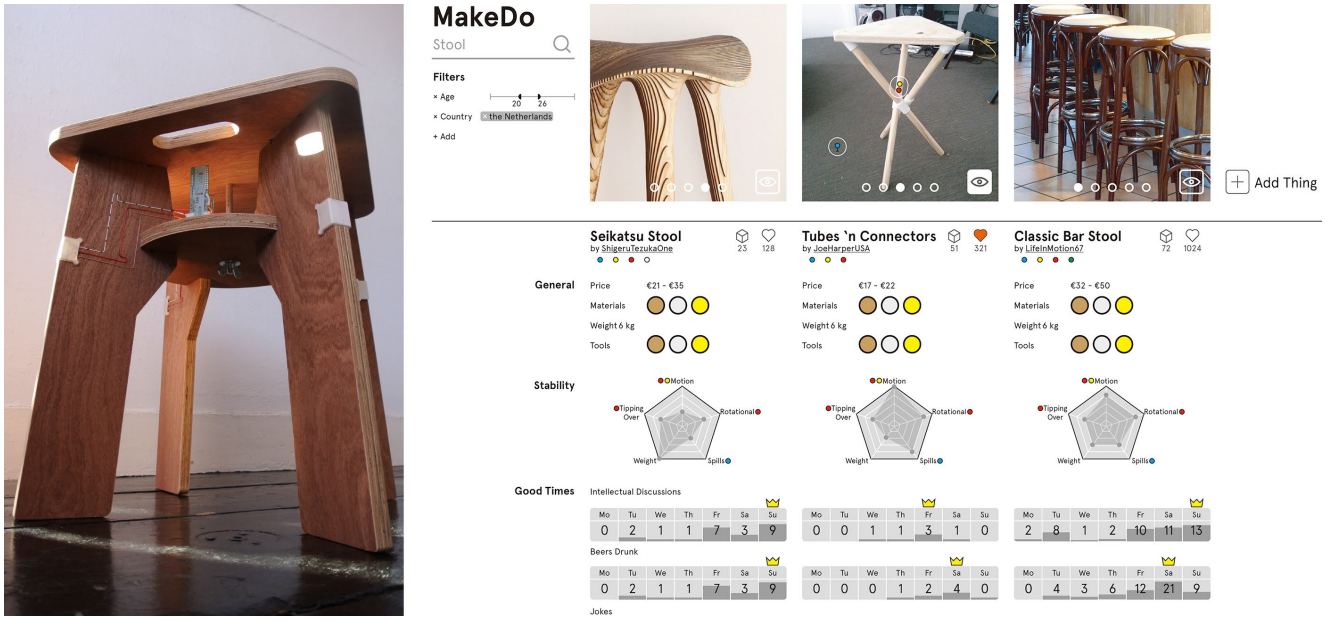

Figure 21. *MakeDo* data sharing platform: Decentralized sharing of insights among makers and things (Amram, 2016).

research and creative potential of things partnering with a broader community of users has been suggested also by the findings of the *Resourceful Ageing* project (Giaccardi & Nicenboim, 2018). This decentralization of insights opens up questions with respect to how to account for the trade-off between social creativity and privacy and security in data-enabled RtD projects.

Conclusion

Data technologies can be used to provoke, to experiment and open up new design spaces, or to test and build theories, just like any other technology. Different RtD traditions and values continue to be at work also in the making and use of connected things. However, as illustrated by examples in this article, data technologies fundamentally collapse the traditional division between participation at design time, interaction at use time and the making of things, or what we used to refer to as the creation and distribution of products and services. This moves the future of RTD practice into the uncharted territory of design as probabilistic outcome.

As examined in this article, data technologies challenge RtD practice along three key shifts: (1) the *agential shift* towards the inclusion of things as partners in design, (2) the *temporal shift* towards always-available opportunities for sustained co-creation and (3) the *infrastructural shift* towards unstable forms of value. These developments fundamentally transform established ways of *doing RtD* in terms of how knowledge is generated, captured, shared and assessed *through* the artifact. The use of data and the inclusion of connected things as partners in the design process

create tighter and potentially never-ending feedback loops between research and design that urge RtD practitioners to move past a fixation with artifactual knowledge as embedded in prototypical yet finite artifacts.

This article has offered a conceptualization of the character and possible role of the artifact in data-enabled RtD practices that profoundly challenges the stabilizing character of the artifact of well-established RtD traditions historically informed by practices of skillful crafting and industrial design manufacturing. In doing so, the article has pointed to the new types of questions that RtD researchers embarking on data-enabled practices should ask, opening up a space also to explore new alliances with traditional ethnographic methods and speculative approaches as glimpsed in the annotated examples of nascent data-enabled RtD practice.

Acknowledgments

This article expands the content of the keynote address delivered at the third biennial Research Through Design (RTD) conference held in Edinburgh, UK on March 22nd, 2017. I feel deeply indebted to Chris Speed and Pieter Jan Stappers for the academic companionship and especially to Johan Redström for giving me the time and space I needed for bringing these and other thoughts to maturity. A sincere thank you also goes to Jonas Löwgren and the reviewers for helping me sharpen my argument and last but not least to all the researchers and students with whom I have had the pleasure to collaborate over the past years in Delft and who have inspired me with their ideas, critical feedback and our many exciting discussions. Finally, I would like to acknowledge the Dutch Research Council (NWO) for funding the *Resourceful Ageing* research program that generated Connected Resources (2015/16734/STW) and Design United for funding the *Things2Things* activities that led to Kash Cups and Morse Things.

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