The Stories People Tell About the Home Through IoT Toolkits

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ABSTRACT
Stories on the home materialize in many different ways. Simple design scenarios of more efficient smart homes exist alongside more articulated design fictions narrating complex domestic futures. IoT toolkits can be used in co-design to narrate design stories together with people. However, there is little attention on the stories captured in the co-creation process. This paper presents a framework describing, comparing, and assessing design stories. We illustrate the framework through the comparison of the design stories captured from three divergent IoT toolkits in co-design workshops. Three dimensions characterize the design stories emerging from our inquiry: complexity (resolution and scope), likeliness (conceivability and feasibility), and implications (acceptability and consequentiality). This framework contributes towards understanding which properties of IoT toolkits support the emergence of what kind of design story. Our findings help designers to frame expectations when using IoT toolkits and to conceive IoT toolkits that support underexplored qualities of design stories.

KEYWORDS
Smart Home, Design Scenario, Design Fiction, Probe, Toolkit, Research Product, Internet of Things, Co-Design

INTRODUCTION
Stories are the basis for how humans think and construct reality [6,51]. Perhaps unsurprisingly, many stories are centered around the home, describing where people have their shelter, the things they value, and the people they love [11,59]. Borgmann’s example of the fireplace—historically a site of warmth and meal preparation—as the center of social interaction, is emblematic of the idea that the home fosters storytelling like no other place [10]. It is thus no surprise that so many designs for ‘smart’ living and the IoT focus on the home as a backdrop for technology-enhanced action [21].

Design stories about the home materialize in different ways. While the ‘smart home’ is a multi-billion market, most stories about the home circle around narrow design scenarios of security, comfort, and efficiency [55]. At the other end of the spectrum, design fictions support the emergence of prospective futures of the home through visionary films [36,57], speculative designs [24], and design fictions [56]. Design scenarios, design fictions, and design stories [13,41] can also be co-created with people through probes [31], research products [48], or IoT toolkits [3,4,14,22,30,32,33,37,38,46]. While research argues for a taxonomy of design scenarios [13,17], design fictions [28,41,56], and research products [48,50], a framework that disentangles the inherent qualities of design stories is missing. This paper presents a framework to describe, compare, and assess design stories that emerge from co-design workshops with IoT toolkits. In particular, some IoT toolkits allow for immediately functional scenarios, while others encourage highly speculative storytelling.

We begin this inquiry by disentangling scenarios, fictions, and tales enacted with design objects, in order to unpack the qualities of these narratives. That we will collectively refer to as design stories. We then compare three deliberately diverse IoT toolkits through the design stories they helped to elicit: the IoT Un-Kit Experience [1], a collection of seemingly uncompleted set of sensors and actuators, and media elements with no predetermined purpose of connection; Loaded Dice [5,38,39] a set of two bespoke interactive cubes, embodying IoT sensors and actuators in a ready-to-use way; IoT Ideation Cards [18–20] a card based toolkit to co-speculate on future IoT. Three dimensions with two properties each emerge from this inquiry: complexity of design stories, explicated through resolution and scope; likeliness of design stories described through conceivability and feasibility; and implications of design stories detailed as acceptability and consequentiality.

We contribute a framework of design stories as a lens to: 1) interpret & compare the stories generated in co-design; 2) frame limitations, expectations and outcomes when choosing IoT toolkits for co-design; 3) understand how the choice of IoT toolkits influences the emerging stories; 4) move beyond mainstream IoT scenarios of more efficient homes up to the future homes people imagine and value. This enables designers to conceive future toolkits with currently neglected properties that support narrating underexplored design stories.
MOTIVATION & METHODOLOGICAL APPROACH
In our own design practice, as well as through IoT meetups [43], a CHI [54] and a Lorentz Center workshop [61] we have witnessed a mind-boggling number of IoT toolkits with a great deal of diversity in materiality. Analogue, card based toolkits [3,14,22,32,44,46] exist alongside digital toolkits [4,30,37] and hybrid toolkits [38,45]. The inventors of these toolkits reported on an equally huge variety of design stories emerging from their use. We wanted to understand the diversity of these toolkits not based on their obviously different materiality (on a physical—digital spectrum), but based on the quality of the stories unfolding through using them.

Our methodological approach is inspired by recent design led comparisons of research products and smart objects in the home [2,29]. We selected three diverse toolkits based on emergent discussions among their designers, a realization that these three toolkits represented three core approaches to toolkit design within the CHI/DIS community, with a commonality that all have been used with participants in co-design workshops in the context of the home. We thus made a collaborative effort, as their inventors, to come together in this paper to reflect on and compare the kinds of conceptual approaches and insights gleaned from these three kits. The IoT toolkits differ heavily in their materiality: IoT Un-Kit Experience [1] is a digital toolkit, IoT Ideation Cards [20] are card-based and analog, Loaded Dice [5,38,39] is a hybrid toolkit. A footing for the subsequent analysis was devised by examining existing literature on design scenarios, design fictions, and tales enacted with design objects. Three dimensions emerged: complexity, likeliness, and implications. These dimensions have been then used to contrast and compare the design stories emerging from using the IoT toolkits.

In what follows, first, we discuss design scenarios, design fictions, and tales told through design objects, revealing how the footings of the framework emerged. Then, we present the three IoT toolkits with each design team retelling two design stories that emerged from their workshops to illustrate the kinds of stories created. After that, we analyze these toolkits to explicate qualities of these stories and to compare them. Lastly, we discuss, how the materiality of the toolkits and the quality of the design stories intertwine. Our analysis is guided by these questions: How can we compare design stories through their complexity? How likely are they? And, what are their consequences and acceptability?

STORIES IN DESIGN
Telling stories is a core human activity and the basis for how humans think and construct reality [6]. As such, stories both mirror how humans think and conversely constitute memory, knowledge, sensemaking, and communication [51]. Humans imagine stories to organize thoughts, and they tell stories to entertain, to educate, to preserve culture, and to negotiate values [51]. Stories help humans to individually and socially make sense of the world, retelling the past and constructing possible futures [6]. The ways in which future technology will be used and its subsequent implications are unknown, because designing new technology creates a future that has not yet arrived. This may yield wicked or unforeseen consequences [34]. As such, design stories allow the exploration of possible futures before new technology is designed. More to the point, stories in design are necessary for contemplating use, context, and implications of future technology – for imagining “what’s next”. Next, we disentangle scenarios, fictions, and tales told through design objects to unravel the qualities of what we collectively refer to as design stories.

Design Scenarios
Design scenarios describe how a particular design enables a certain actor to achieve a certain goal [13]. They can report on current use or depict hypothetical future use. When depicting current use, they emerge from observations, field studies, or ethnography. Here, they are used to reconstruct how people use or appropriate existing technology in real-life contexts [17]. As they detail issues and problems in actual use, they can subsequently be used to propose future objects that may remedy these issues. Such a design scenario then depicts a hypothetical use, often framed as a promise, relating to an existing technology. The ubiquitous mantra of a more efficient smart home is the perfect example. Here, an existing smart object is described through a fictional vignette to explain the benefits of using this object, with the overall goal of “enchancing the user” [49]: To sell the product. When they depict fictitious objects, design scenarios project future use. Such scenarios are created around a fictitious main character using a fictitious object to accomplish a fictitious goal. Design scenarios usually describe use in order to guide future implementation [13]. The narrative value of design scenarios is generally rather limited [42]. Largely descriptive, they do not account for further questions regarding the inherent values and potential implications of design scenarios.

Design Fictions
Design fiction as a practice has gained significant attention [8,9,15,16,35,41,42,56,58]. And while it is still open to debate whether it is a narrative practice [9,56] or a design practice [8,35], it aims to explore the implications of possible futures. These possible futures are well contextualized, not only focusing on the ‘scenario’ but also on peripheral activities [57]. Bruce Sterling defines design fiction, as “the deliberate use of diegetic prototypes to suspend disbelief about change” [47]. As such, design fiction is “a method of creating dragons, letting ‘em loose, see if they disrupt anything”. As the notion of dragons suggests, diegetic prototypes are not common prototypes. They are narrative and intangible prototypes created by designers or co-designers. To elaborate a design fiction, a number of design stories of various complexity need to be told [56,58]. First, for design fiction to work, a number of connected design stories are told in rich detail to vividly illustrate cornerstones [8] of a fictional world. Taken together, these design stories are capable of encircling a comprehensive fictional world [8,16]. Second, this storytelling practice also relies on the people consuming these design stories. They need to interpret and subsequently assemble them into an individually coherent pathway that
defines a comprehensive fictional world. Accordingly, Coulton et al. argue that a design fiction is a “map of our fictional world that can be explored in a variety of ways and a narrative, if used, would be a distinct path through this fictional world.” [16]. That is to say, several design stories of various complexity produce inputs for a fictional world to emerge. These stories do not define this world per se, but support world-building on the level of an individual telling his or her own story. A design fiction is both the world containing several design stories and simultaneously the individual pathway in which an individual connects these design stories into an individual design fiction. Overall, design fictions engage people in a “what’s-next mode” to foster imagination and to consider possible future worlds. They allow to reflect on likeliness and acceptability of design stories.

**Telling Design Stories Through Objects**

If design fiction makes it possible to explore different possible futures through storytelling, why would it be necessary to actually design research objects? It has been argued that design stories have advantages over research objects. The latter are time consuming, labor intensive, expensive, and unreliable, whereas narrative prototypes work seamlessly through storytelling [35]. In contrast, it has been argued that “designed objects tell stories” [8]. Design-research objects are beneficial because they directly involve people in imagining, reflecting on, and telling design stories through material exploration. In particular, design workshops benefit when people tangibly explore the materiality of research objects [25,50,52]. Here, people can narrate design stories through tangible exploration of possible functionality, interaction, aesthetics. This engages people in a multisensory “what’s-next mode”, enabling them to tell design stories in higher resolution and wider scope than when reflecting on narrated stories alone. To involve people in storytelling through material exploration, a range of genres of research objects exists, including probes, research prototypes, and toolkits. Differences notwithstanding, they overlap significantly in their aim of engaging people [50] in narrating design stories of various complexity and likeliness, and reflecting on consequences.

Research products are explored just as actual products and are not made to be tested for mass-production. This makes it easy to engage people in narrating stories of use and simultaneously in narratively constructing worlds around these products [48]. Probe studies [26] and speculative design [24] are similar methods to the same end. Their materiality is preliminary and capable of engaging people in diverse storytelling [27]. They invite people to reflect openly on possible future worlds through hypothetical interventions, exhibitions [24], or video [36]. The quality and diversity of the design stories emerging from these explorations suggests the importance of the materiality of research objects for telling design stories. In any case, research products, probes, and speculative designs exist to explore possible future worlds without ramifications. Toolkits allow people to construct research objects themselves. Their purpose is to support co-designers in understanding possibilities through exploration and facilitated making. Toolkits are useful for getting people to narrate design stories directly and to construct worlds in which these stories have a place. Especially for design workshops on the home, a plethora of analog [3,14,22,32,33,44,46], digital [4,30,37] and hybrid [38,45] toolkits exist. Toolkits are remarkably versatile research objects. They allow people to prototype design scenarios of immediate use with a high complexity, while simultaneously allowing people to reflect and speculate on the wider scope of a world in which they would exist. The design stories emerging from employing toolkits may follow a straightforward narrative that is immediately beneficial. But in constructing this, people also construct the world around it [1,5] and unwittingly create possible implications: They create accidental design fictions.

So far, we argued, that design stories are the main way in which people imagine future technology for the home and that these stories exhibit a number of qualities, but that a framework to unpack and reveal the broader dimensions of design stories told through design scenarios, design fictions, and tales enacted with design objects is needed. In what follows, we will investigate the nature of design stories for the home as told with IoT toolkits.

**PRESENTING THE TOOLKITS AND STORIES**

We first present the three IoT toolkits, accompanying co-design workshops, and two design stories each. We will then discuss these toolkits and design stories in relation to each other. In so doing, a detailed framework of the qualities of design stories will emerge. Lastly, we outline how toolkits support and influence people’s storytelling capabilities for narrating stories about the home.

**IoT Un-Kit Experience**

The IoT Un-Kit Experience [1] is an approach that supports a contextual exploration of IoT in the home with attention to engagement within a network of intimate social relations. In designing the toolkit, we started from an observation that many existing toolkits do not provide high-level functionalities and only focus on low-level building blocks. We noted that participants often spend a lot of time fiddling with toolkit parts, combining them to create interesting functionality, but find it hard to move past technicalities and explore how a design may support their goals, values, and social connections. The Un-Kit includes an initially unconnected and seemingly incomplete set of high-level sensors, actuators, and media elements capable of recording, sharing, and playing content. The sensors, with electronics covered in fabric, are designed to be unintimidating, to be held and contemplated, rather than connected. The toolkit was used in co-design workshops, with participants from various age groups, conducted in their homes to encourage them to take ownership of the design process and actively explore roles for IoT in their lives and capture their stories about ‘future homes’. We opened the workshops by describing examples of IoT designs that our lab had produced, such as the Messaging Kettle [12] and Ambient Birdhouse [53]. We explained how both
designs could be deconstructed into IoT components (temperature sensor, audio recorder, a screen on which users can hand-write notes, and a ‘lava lamp’ to represent presence) while showing the same elements from the Un-Kit. We then asked the participants to walk us around their homes, reflecting in each corner on what activities take place there, their purpose and significance, the people with whom they connect, and the potentials for an interesting IoT design. Having developed an idea through dialog led by the participant, a researcher then prototyped it just in time, using the IoT Un-Kit elements to make it come to life. By the end of the session, each participant was able to focus on one IoT design to support one particular activity or connection.

**Fig 1: IoT Un-Kit Experience elements**

*Smarter Marcus Aurelius*

M lives in a house in the outskirts of Brisbane, Australia, with her mother, grandmother, a dog, and three chickens. After showing us around her house, M focused her reflections on her study space in the basement of the house. This is mostly her own and consists of a large rumpus room with a couch; a TV set; a library full of books, DVDs, and collectibles; and a study desk with a PC. M is an undergraduate student of ancient history and shares a passion for Roman history with her paternal grandfather, who lives in the USA and whose health is slowly declining. M’s study space is where thoughts of her grandfather emerge more distinctly, such as when she encounters events and characters that she may want to discuss with him. This is unfortunately becoming more difficult as he is now forced to stay in bed for large parts of the day, sometimes wearing an oxygen mask. His bedroom is on a different floor of the house from where he would use to Skype with her. This, in addition to the time-zone difference between USA and Australia, makes it virtually impossible to organize Skype calls. M decided to explore a design that could make her feel more connected to her grandfather. She owns a small souvenir bust of Roman emperor Marcus Aurelius that she bought during a trip to Rome. She decided that the bust was an object that she very strongly associated with her grandfather by virtue of their common passion. Her idea concretized in a ‘smart bust’ that we prototyped on the fly using the toolkit. The Smart Bust embeds networking electronics, a light actuator that lights it from behind to create an ethereal glow, and a small text display as a proxy for a desired scroll-shaped display through which M could share short texts with her grandfather. She would send texts from her PC when studying and finding a quote she would like to share, for example. The text would then appear on a similar scroll screen with glowing bust at her grandfather’s bedside.

*The Fridge-Magnet Synchronization*

J lives with his family and found it difficult to focus on a particular aspect of his life he wants to enhance with IoT. There is a corner where he practices his trumpet. Another hint came from the fact that J owns a dog that is afraid of thunderstorms, a phenomenon occurring quite often in summer. This is a source of worry, because the dog would run away in fear during a storm. Eventually, J shows the researchers into the kitchen, where a number of magnets are attached to the refrigerator that can be seen from the living room. One magnet is from the local community pub, where J, his family, and neighbors meet every Friday. This tradition has been maintained for many years and is very important for J, because it connects him to neighbors and the people he grew up with. The bartender knows them by their first names and pours their favorite drink as they walk through the door. J fears that a busy lifestyle could hinder this tradition. When returning from work on a Friday, he is often too tired to go to the pub. But if a customized device were to visualize the presence of family and friends at the pub, or their intention to go there, he may feel encouraged to go. J imagines a device that would light up on a Friday afternoon to encourage everyone in the family to go to the pub. The system J imagines would be off for the whole week and turn on automatically at 3pm on a Friday. When J is back from work, he imagines himself glancing at the display to see who’s going to the pub, who’s there already, and who’s not planning to go. If J decided to go to the pub, he would change a setting on the device to light up his ‘presence’ on everybody else’s fridge. At 7pm, when the kitchen at the pub stops serving food, the device turns off automatically until next week.

*IoT Ideation Cards*

The IoT ideation cards are an iteration of previous work on creating design tools for IoT concept generation [19,20]. The card deck creates a visual system overview of a product and/or service combining tangible and intangible elements. The IoT Ideation Card deck is designed such that it can be personalized depending on the context in which it is used. The deck consists of initially blank cards that are filled out during idea definition. The deck consists of four types of cards, which allow co-designers to explore IoT concepts using an actor network theory-style breakdown: Person cards: persons or groups relevant to the project context – the target audience, for example. Environment cards: the contexts related to the problem area – the ‘living room’, for example. Object cards: physical objects relevant to the project context – a ‘chair’ or the ‘front door’, for example. Interaction cards: placed between person, object, and environment cards and defining the relationships between them. They can be labelled as physical, data-driven, sensor-driven, and can be input or output related.
The IoT Ideation Cards do not impose a strict rule set for ideation sessions. They are primarily used to structure the thoughts of co-designers with diverse expertise and backgrounds. The cards have been used in various situations, from educational to corporate business-modelling workshops. In all cases, a four-step process was followed in order to move from problem definition to fully visualized system overview. Problem definition: Co-designers start an ideation process by defining a ‘how-can’ question. This is done using a template together with a set of person, context, and inspiration cards, randomly matched to create a central challenge. Card-deck customization: Depending on the challenge, a customized set of person, environment, and object cards are created. They form ‘starting points’ for solving the problem. Solution network definition: By exploring the cards created, co-designers explore possible solutions. They are free to add or remove cards from their initial deck as needed. Interaction definition: By adding interaction cards, the system is made explicit. Close attention is paid to tackling critical elements, making it clear which aspects happen physically or digitally. The IoT Ideation Cards impose no preference regarding technology, the intention is for them to focus on the context of use and the aim is for them to stimulate people in defining products with meaning for the intended target audience.

Fig 2: IoT Ideation Cards

Just-In-Time Local Meals

This idea was defined during a hackathon session, where the ideation cards were used to kick off the initial exploration of ideas. The workshop focused on out-of-the-box thinking. The story behind this idea started from the trend of local, small-scale farming. Increasing numbers of people endeavor in rooftop farming in cities, often producing very specific varieties of vegetables. These vegetables could be an interesting resource for chefs working in local restaurants. The idea was for chefs to be able to source their ingredients fresh, based on the menus or dishes they make, from various rooftop farms in a city. The vegetables would be harvested in a just-in-time fashion, providing fresh produce that would be consumed right after harvesting. Since the harvesting happens locally, in small quantities, and at the last minute, drones would be used to fly to different rooftops and gather all ingredients needed based on the meals ordered. The rooftop gardens, the garden owners, the chef, and the drones would all be in constant digital connection with each other in order to track growth, availability of produce, and meals on order. This story involves a complex network of actors and can be broken down in two large parts: first, the tracking of the rooftop gardens (soil quality, vegetable status), and second, the availability of local ingredients the chefs can use.

Walking Cane for Urban Exploration

This story focuses on allowing older adults to explore the urban environment of a city for themselves, in contrast to large groups of older adults that typically travel by coach and only get to see things where the tour guide takes them. In this story, the central object would be a walking cane with a GPS connection. The cane’s primary function would be to guide the older adult through the city. The cane would change the route depending on the vital signs of the older adult. In this story, it would mean that when the older adult feels tired, the cane would guide the older adult to places with more public benches or with sanitary facilities available. The cane would not ‘force’ this behavior on people, but would mostly suggest options by dynamically altering the indicated route. In order to guide older adults, the cane uses tactile feedback (vibration) in combination with subtle lights. The secondary function of the cane would be to allow tour operators or even family members to remotely monitor the older adults. If needed, they can also be geolocated in case of an emergency. The intention with this product is to increase the level of autonomy of an older adult in the chaotic urban environment. A challenge this story faces is where the boundary lies between being experienced as a tracking device rather than a supportive device that helps in exploring new spaces.

Loaded Dice Toolkit

The first part of the hybrid Loaded Dice [5,38,39] consists of a sensor cube and an actuator cube. The sensor cube has a different sensor on each face; the actuator cube has a different actuator on each face. Both cubes interact wirelessly with each other: the face of the sensor cube senses and communicates the accrued sensor data to the upward-turned face of the actuator cube. Turning a different face upward activates the sensor on that face. The actuator cube works in the same way. The sensor cube has one of six sensors on each side: potentiometer, microphone, infrared thermometer, lux-meter, passive infrared detector, and ultrasonic transceiver. The actuator cube has one of six actuators on each of its six sides: Peltier element, vibration motor, LED bar graph, fan, loudspeaker, and power LED. Workshop participants need no prototyping skills and can come up with sensor–actuator combinations with the simple turn of a cube.

In co-design workshops, Loaded Dice are accompanied by a card set that permits the prototyping of scenarios for IoT communication in the context of the home. There are cards in the following categories: Goal, Space, Actor, and Properties. The cards are laid out on a table to define design stories as follows: First, a Goal Card is chosen as a theme for the story; all subsequent cards are then used to refine this theme. Second, one or more Actor Cards are used to depict the actors involved and Space Cards are used to define the spatial properties for the IoT scenario. Once these cards are laid out,
The Anger Meter

One group of co-designers identified the complaints of their neighbor as the basis for a smart object. The neighbor often gets angry at them for making much noise in their home. The group wanted to prevent an escalation of the conflict and avoid legal consequences. Hence their goal was to find a way for him to communicate his annoyance directly, so that they would be informed and could react appropriately. The neighbor did not participate in the workshop, but the group dedicated the story to him and tried to take his point of view when choosing Property Cards to describe how he would want to express his feelings. Eventually, they settled for the properties “direct”, “targeted”, “fast”, and “angry”. On the receiver side, they chose “binary” and “graded”. They assumed that they would need to know if the neighbor was angry or not, but not necessarily the amount of anger. In the second part of the workshop, co-designers discussed technical components of their smart object and created The Anger Meter, transforming the neighbor’s subjective emotion into objective information. By playing around with Loaded Dice, they chose a potentiometer for the neighbor to ‘dial up’ his level of annoyance. In contrast to this, they discussed how they could avoid overuse and added a microphone to the concept. Thus, they could compare the neighbor’s perceived noise level to an objective measurement. Co-designers conceptualized a smart actuator device for their end, which communicates both the neighbor’s anger and whether their noise level is within legally allowed parameters. They stated that the actuator device should be hard to ignore and prompt an immediate reaction. It would need to vibrate and also use an alarm light to signal when the legally allowed noise level is exceeded. Co-designers imagined that the information from the two noise measurements would also be sent back to the neighbor for him to be able to reflect on it and to ask himself whether he was overreacting.

TELLING STORIES THROUGH IOT TOOLKITS

To answer the questions raised in Stories in Design, we now disentangle the qualities of the design stories presented. We first describe technicalities around complexity and then unfold qualities of likeliness and implications of these stories.

Complexity of Design Stories

First, we will look at how refined these stories are and how we can compare them through this complexity. Coulton et al. have proposed “zoom” [16] to describe the space a design story encompasses: We can zoom into the details of a story or zoom out to a view of the world within which the story exists. To distinguish stories based on their complexity, we borrow the notion of fidelity from prototyping research. It explicates two distinct qualities of an otherwise shapeless complexity [40]. We define resolution as the amount of detail a story narrates: If a story is of high resolution, it contains a great deal of detail and is played out in concrete terms. Scope refers to the size of the world described in the story. If a story narrates a world with a broad horizon, it is broad in scope. A story with a very specific spectrum of aspects depicts a small, explicitly defined world and is narrow in scope.
Both stories from the IoT Un-Kit Experience are of high resolution but relatively narrow scope. They are relatively detailed in how they are formed and what they should help to achieve. In addition, it would be relatively easy to actually implement the smart objects proposed. If built, these individual objects would exist in a small number of households and most probably would not disrupt the world around to an extraordinary degree. The conundrum is that the stories are relatively detailed in how they would be spelled out, whereas the world they exist within would not be particularly disturbed. Looking at Smarter Marcus Aurelius, we see that all the technical building blocks of the IoT are provided by the toolkit. And while the story does not focus on technology, the complexity of the story is bound by the materiality of the toolkit. The story sheds light on the lived experience and the longing for social connections of one particular person with her grandfather. The toolkit proposes technology that is tangibly real. In doing so, it provides a way for detailing a story of high resolution that depicts emotional connection within one particular place, for two particular people with their own intimate and personal world. The story makes sense only in this context, for these specific people, their personal circumstances, and their specific social connection. At the same time, it is of no real relevance to anyone other than the person who created it and her grandfather. As such, the scope of this story is very narrow. The world of the story is clearly framed and bound by the context of the very family in which the co-design workshop took place. This is further supported by the way the toolkit was appropriated in hands-on workshops within the homes of the co-designers. By tangibly exploring concrete technology, it can subsequently move into the background. In contrast to this, the story Just-In-Time Local Meals opens up a broad world, where drones are a usual sight and where the regulations relating to drones have been taken care of. This is to say that this story cannot be told without a world in which there is city-wide networking of different actors—including plants, houses, chefs, and garden owners—and, from the story, it would be common for society to rely on an infrastructure of technology more complex than today. The communication infrastructure in this imagined world is only implicitly depicted. The implied level of sophistication is high, but not specifically narrated. It would, in turn, be relatively easy to imagine radically different services within the broad world sketched out by the story. Further similar services based on that same implicitly described infrastructure are easy to imagine. How the system of ordering and harvesting would take place remains less detailed. This is to say that the story is of low resolution. As such, it is no contradiction, but rather the characteristic feature of this first quality of complexity, that stories of low complexity can fold into and be part of stories of higher complexity. This is what has been referred to as “world building” [16], where stories of high resolution and small scope co-exist and connect to each other to initiate a story of broader scope. Complexity is a technical dimension of the narrative, because there is no value judgment involved in spelling out this dimension. However, the complexity of a story influences all other dimensions. The following dimensions of likeliness and acceptability warrant a certain level of complexity: The higher the resolution, the easier it is to estimate the likeliness. Scope, on the other hand, has an impact on which consequences and implications are touched upon or tapped into by the story.

Likelihood of Design Stories

The dimension of likeliness is a judgement based on time, resources, and knowledge. Likelihood relates to practical questions of how possible it is for a story to come to life—now, within our lifetime, or in a faraway future. Sterling’s notion that “you can ponder many a design text without ever finding [...] experimental proof.” [56] is fundamental to this dimension. We do not need to put stories to test to understand their consequences. But since design stories allow us to reflect on their implications, we need to grasp whether, how, and when a design story could actually be brought into life. To separate the qualities of likeliness, we consider the conceivability and the feasibility of a design story. We define feasibility as how achievable a potential future is based on the certainty of technical and scientific knowledge. It is based on objective knowledge and considers how a story could possibly exist in the world. With feasibility, we can ask whether a story would be feasible with current technology or whether it follows the rules of physics as we know them. Conceivability refers to how we are able to actually imagine a potential future. This is a subjective quality, as it depends on what an audience is willing to or could be persuaded to believe. In particular, how plausible is the story to the audience? Would an audience believe designers or policy makers could put the story into action, and if so, when and how?

The design stories narrated in the TV series Black Mirror [7] have attracted attention due to the fact that they are both conceivable and also rather feasible, which makes episodes rather uncanny. But what does that say about the toolkits and stories of our study? The IoT Un-Kit Experience is exclusively based on existing and functioning technology within concrete homes of people. This makes it logical for stories to emerge that are entirely feasible for our current understanding of the world. Moreover, the ability of immediate prototyping—which is part of the toolkit’s workshop—demonstrate this feasibility. The story of Smarter Marcus Aurelius persuades the audience of its feasibility by means of presenting a functioning toolkit. Also, with Fridge-Magnet Synchronization, building blocks for the IoT are readily available and it is a story about smart connections that are designed for “now” and for integration into one family’s current life. Both stories present their social context in rich detail and both circle around close social connections of the people creating the stories for situated, and intimate communication with their family members or friends. This also reflects the context in which the co-design workshops took place and makes it easy to conceive the stories. While Loaded Dice also consists solely of existing technology, both the form and the dedicated arrangement of IoT building blocks make the stories emerging from it somewhat lower in resolution compared to the IoT Un-Kit Experience. The
stories are still highly feasible, but also less conceivable due to their greater vagueness. The designers of both stories treat the people in these stories as alien to their stories. Yet these co-design workshops also took place in the co-designers’ homes. This is contrary to the intimate and meaningful social connections to beloved people that are carefully crafted with the IoT Un-Kit Experience. Moreover, a story like The Automated Rent Debtor is certainly feasible, but the escalation from fact to fiction depicted in the story raises questions regarding its conceivability: Who would design and built a smart service that is likely to be unethical, and who would move into a housing project punishing residents?

This grading of both qualities continues with the stories told through the IoT Ideation Cards. Both stories depicted here are even less conceivable compared to the stories from the IoT Un-Kit Experience. Walking Cane For Urban Exploration is a large creative leap, it exists in a world where smart everything exists, and it would not come as a surprise if a startup were to put such a product on the market in the foreseeable future. It is feasible, at least in the near future, but the story raises a number of questions regarding conceivability. The story includes a number of unresolved what-ifs. For example, it considers older adults on tour buses with mundane walking canes to be a likely audience for a technology that is not yet feasible. We argue that the way in which the toolkit encouraged participants to come up with highly innovative solutions does not pass muster for conceivability. A similar observation can be made with the technical components imagined for the Just-In-Time Local Meals story. While not challenging the laws of physics, it is unfeasible, mostly because none of the technicality is presented or even presentable in detail. This also relates to how the workshop was conceived: unbound both from any concrete home and from the concrete prototyping capabilities of the other toolkits.

By not defining technology in sufficient resolution upfront, the outcomes are sometimes perceived as unrealistic from a technological point of view. From a human point of view, they propose inspirational product concepts that can be iterated upon in prototyping or further design cycles. The greater the resolution of stories presented here, the more conceivable they are. But as the scope remains small, it is less easy to relate them to the world for others. Likeliness is a value judgement for distinguishing between making and imagining. However, the overall complexity of a story and its likeliness intersect. In particular, the greater the resolution of a story, the easier it gets to understand if and how it would be feasible, because the story can be held accountable for the technology presented with the toolkit. Here, the practicalities of a story are put to test and can account for feasibility.

This ultimately raises the question of how unfeasible a design story can be while making sense for designers. It might be conceivable that “technology [...] can eventually rot and go away all by itself” [56], yet how can designers use the qualities of likeliness to create meaningful stories?

**Implications of Design Stories**

Design stories can describe and anticipate actual, future, or hypothetical use. Considering equal likeliness, how does a design story allow us to imagine and reflect on consequences, and how does it question acceptability? On a very general level, Sterling proposed the metaphor of “creating dragons, letting ’em loose, see if they disrupt anything” as a way for storytelling to encourage thought about the implications of future design. We think it necessary to consider implications not only as general what-ifs, but to distinguish between the short-term acceptability of a story for an individual and how the story, if realized, would influence the world within which it exists. To account for the implications of design stories, we propose the qualities of acceptability and consequentiality. Both are future oriented and refer to immediate and future ramifications. Acceptability is defined as the short-term consideration—how a story would impact the people involved in the story. It relates to the question of whether a person would want to live in that particular world. Consequentiality, on the other hand, refers to the long-term consequences of a world in which this and other similar design stories would be commonplace. Consequentiality also relates to the question of into which complexity this story would eventually cascade.

Key to the understanding of implications is a consideration of the world in which a story exists. Both stories of Smarter Marcus Aurelius and Fridge-Magnet Synchronization exist in their own narrow worlds of a single household, in which the co-design workshops took place. Furthermore, the materiality of the IoT toolkit frames both stories within a design space of graspable and existing technology. This is to say that it may be straightforward to infer implications. They may be not as severe as the implications of completely speculative technology. Accordingly, the worlds the stories are able to influence are rather limited. Both The Anger Meter and The Automated Rent Debtor explicitly put problematic behavior of the people involved in the foreground. The Automated Rent Debtor suggests behavior nudging as an outcome. However, while different in the sense that either design story could be described as good or bad for the people involved, the world that would be disturbed is relatively narrow in each case. It remains to be seen whether the people involved in these examples would benefit or lose in a world where these stories would be real. The strength of the worlds opened up by these design stories is precisely the combination of their small scope with their high resolution, however. The detailed depiction of exactly how the story would unfold does allow other potential readers to empathize with the people in the stories. Moreover, it is possible to relate to how this technological deployment might feel. In particular, how would it feel to get only cold showers in comparison to staying close to family over distance with a habituated object? These detailed, yet narrow stories emphasize how a smart story would elicit acceptance on a personal level for a person.

To look at long term implications of these scenarios, we could assume that a lot of people would use such or similar
devices. However, we argue that social protocols would not be overly disturbed. Although The Automated Rent Debtor makes it explicit that it would unwillingly force a smart service onto a person that would have consequences for that person, it has no real impact on readers. Because, as it is told through, it is very much likely that the story exists in a world where everybody could design a device for their home. It does not necessarily point to a world in which everybody would use this very specific device. The stories emerging from the IoT toolkits that let people imagine situated design stories are indeed positioned in the present time: they can be designed and deployed with existing technology right away and seem not to warrant new ethical norms or law (although they are ethically questionable on an individual level). They are not dragons, but are situated within reasonable and actionable boundaries of time and consequences.

On the other hand, with Just-in-Time Local Meals it is easy to see that a lot of regulations would need to be fulfilled in order for the design story to come to life. This story paints a superficial and broad scope of a world where many things are different to the world we know. In answer to the question of how consequential this story would be, it is comparable to how people have adapted to renting out part of their homes to strangers. Selling excess crops certainly seems like a reasonable thing to do, but the story opens up a world where many more parts of the home are commodified than is the case today. Because this story is broad in scope, it has the potential to raise a number of potential consequences. Here, the complexity of a story and its implications intersect: the broader the scope of a story, the more impact a realization of that story would have. As such, the qualities of implication are value judgements: How acceptable is it for us individually, how consequential for the overall world in which the story exists, and how would it be to live in this world? The dimensions also take into account the breadth of societal change: If it would be acceptable to live in the world of the story, would the ensuing world be consequential, and how could we tell? Individual acceptability and global consequentiality are interconnected. In particular, people might overestimate the short-term consequences and accept a story, perhaps for its convenience, but they underestimate the long-term consequences and would have not accepted it. Both qualities push each other along a slippery slope of implications: Every step of thoughtless acceptability goes part of the way toward a perhaps unknown consequentiality. Therefore, every story will inadvertently indicate both qualities of implications. Here, a high resolution might conceal consequentiality by virtue of tempting acceptability.

RELATING QUALITIES OF DESIGN STORIES TO THE MATERIALITY OF THE IOT TOOLKITS

We have proposed complexity, likeliness, and implications as dimensions for comparing and contrasting design stories emerging from IoT toolkits. But contrasting these dimensions does not mean that some stories are more powerful than others. Rather, the toolkits presented allow people to engage in telling meaningful design stories. Notwithstanding this similarity, different toolkits yield different stories. The Un-Kit produced stories of high resolution and low scope that can be immediately integrated into peoples’ lifeworlds. Through IoT Ideation Cards, stories of low resolution and broad scope surfaced that opened up deep questions of likeliness and implications. Finally, with Loaded Dice, stories were told that fall in between the scope and resolution of the other toolkits, but unfold the diversity of the ‘home’ in different contexts. We argue that the different materiality of toolkits does allow designers to scaffold people’s ability for storytelling on various levels of complexity. With Un-Kit, researchers started with a situated account of understanding people’s living situations and objects, places, and routines that are important for them. Only then was the toolkit used to support storytelling through objects and routines. Naturally, the stories were high in resolution, completely feasible, and highly conceivable. Yet the stories were of high acceptability for the co-designers involved because they touch their own intimate lifeworlds. Because of this careful negotiation, they are also of rather unproblematic consequentiality. The technical building blocks of the Un-Kit were used by co-designers and researchers. Here, collaborative storytelling helped tune into the individual ways of how people make up their homes. This made it easy for people to imagine how a particular smart object would be embedded into their homes.

In contrast to this, IoT Ideation Cards support the creation of stories that are “far out” and make it possible to dream up integrated services that do not fit with our technological infrastructures. Looking at the materiality of the toolkit, cards embody technology. Telling stories about some future home was thus relatively unproblematic, because the co-designers were not connected to their own homes, but to an impersonal, hypothetical home. This abstract materiality lead to stories low in resolution, but opens up many questions regarding likeliness and implications. From the workshops with Loaded Dice, idiosyncratic stories for specific living situations emerged that were limited in scope and resolution. Yet they unraveled particular stories people tell about their homes. They are feasible, but not conceivable in the context of a larger scope. We argue that the particular limitations of Loaded Dice supported the emergence of this kind of story. Compared to Un-Kit, Loaded Dice is restrained in terms of connecting IoT building blocks that allow high resolution to develop. It is also restrained compared to IoT Ideation Cards that support storytelling free of technical limitations. This middle ground is also the biggest asset of Loaded Dice. Being situated halfway on both scales of the complexity dimension, the qualities of likeliness and implication fluctuate and open up questions that relate to current issues regarding the home. This is a departure from both the intimate and situated questions arising from Un-Kit and the hypothetical ones arising from IoT Ideation Cards.

This now questions, whether there can be a tradeoff between the specificity of the kit and the openness and relevance of the story. The stories we analyzed indicate that the toolkits individually allowed for the creative exploration of very
different qualities. We believe this relationship should be considered and embraced by toolkit designers. Abstract materiality fosters creativity in terms of telling open stories, and these in turn foster imagination of a broader future world. More concrete materiality fosters reflection on intimate, personal, and situated future-oriented stories. We also acknowledge that the design stories are not only influenced by the materiality of the IoT toolkit but also by the environment in which the workshop takes place, how the co-design process is facilitated, and what is expected from participants. The way co-design workshops are conducted inevitably changes every time. As such, there will never be sufficient proof of whether the materiality of the toolkits caused the stories. Our work is intended to encourage design researchers to try these or similar toolkits in similar or different situations and to thoroughly reflect on them through our framework.

OPPORTUNITIES FOR FUTURE RESEARCH AT THE INTERSECTION OF TOOLKITS AND DESIGN STORIES
The accounts of the three toolkits and the six stories emerging from them can serve as an indicator of how the materiality of toolkits lead to design stories with different qualities. It seems that designers tend to prefer toolkits of their own design [60]. This raises questions about how to design future toolkits, and may inadvertently lead to an underrepresentation of story qualities that are outside the toolkits’ scope. The framework of design stories opens up a new way to match co-design goals with material that will help achieve that goal. There is an opportunity for design to categorize IoT toolkits on their respective dimensions and to compare them in practice to understand and categorize the stories emerging. Further, as different toolkits help develop stories of different dimensions, we propose examining the dimensions emerging from our enquiry by means of one toolkit used in different contexts. This could help understand which aspects of all dimensions a given tool could ultimately unfold. This would also provide an opportunity for testing current dimensions in the light of cultural, geographic, and societal values. Designers of toolkits need to acknowledge the dimensions of stories that their toolkits have a blind spot on. Our analysis is also a starting point for making an informed choice of a particular toolkit with reference to the context of use. In terms of complexity, there is an opportunity for broader and narrower toolkits. Narrow toolkits would be able to “zoom in” and carefully inquire into incredibly detailed, highly situated domestic contexts, and to tell stories of high resolution. Toolkits that support a broader scope would make it possible to negotiate the implications and likeliness of stories that question grand narratives of what the ‘home’ is. They could look behind narrow narratives of efficiency for the smart home. We need toolkits that are able to traverse such complexities. Considering likeliness, a toolkit that permitted the imagining of highly feasible yet completely inconceivable design stories would make it possible to inquire into the futures people like to tell. With such toolkits, we could imagine design spaces that were feasible but inconceivable. Would this make sense for design? Looking at storytelling critically, one of the stories presented here explicitly but inadvertently raised ethical questions. How can toolkits support the negotiation of critical questions regarding acceptability and consequentiality? Such toolkits would need to ask what-if questions on an individual level to inquire into acceptance and then transpose these questions toward general consequentiality. Such toolkits would allowhands-on approaches to critically reflecting implications. If future HCI design research accounts for those questions, designers and users of toolkits will be able to reason what dimensions of stories they would like to explore and choose an appropriate toolkit from that point. The toolkits we featured here are generative and experimental. They fostered storytelling of possible futures where more technology can do more things. For future work designers need to actively question and tweak the materiality of their toolkits in order conceive IoT toolkits that support currently underexplored design stories.

With this paper we articulated a novel way of analyzing co-design of emerging technology. Our inquiry focused on a design stories framework through a situated analysis of three emblematic IoT toolkits. This leaves a detailed comparison of plenty other IoT toolkits unaccounted for. Likewise, we have chosen to focus our inquiry on stories on the home, arguably a very specific genre for co-design. Yet, the home is the most valuable place for many people with a great deal of diversity. It is thus a valuable site for co-design and the emerging design stories are particularly rich and diverse.

In this regard, we wish to position this paper as a first grounding of the design stories framework and aim to expand future work to other emerging technologies and design spaces such as wearable computing, autonomous cars, blockchain, augmented and virtual reality.

CONCLUSION
We presented a framework to understand design stories, illustrating it through the analysis of design stories emerging from co-design workshops with IoT Un-Kit Experience, Loaded Dice, and IoT Ideation Cards. The stories presented can be positioned on the dimensions of complexity, likeliness, and implications. Our analysis revealed that the materiality of a given toolkit has a strong influence in shaping the stories emerging from it. We provide insights into how the choice of different toolkits for co-design changes the stories that can be expected to emerge from the workshops. Future work is needed to further support designers in framing their expectations when using IoT toolkits. There is also an opportunity for toolkits that support qualities of design stories that are currently overlooked by existing toolkits. This also means that while designers need to use their own toolkits more, they also need to use those of other designers more so as to draw conclusions about which story dimensions they help to emerge in different contexts of the home.

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