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T4Tags 2.0: a Tool to Support the Serendipitous Use of Domestic Technologies

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Abstract. We present an iterative design exploration to support *serendipitous uses* of technology: quick re-configurations of the domestic environment to address inhabitants' current needs, whether they are transient and ephemeral or they present a more habitual character. As a result, we developed T4Tags 2.0, an open-ended toolkit for programming web-connected and versatile physical tokens that embed different sensing technologies (e.g., NFC, physical buttons, motion and environmental sensors) and can be easily integrated with existing artifacts. The design of the toolkit was informed by fieldwork that provided design drivers for domestic technologies to being repurpose-able or appropriate-able, through features such as end-user programming of devices' behavior and crowd-fueled appropriation by sharing 'recipes' of programmed tokens. A user study with three families provided insights on the usefulness of the system and the recipe sharing functionality. We furthermore discuss opportunities and challenges, reflecting on the tradeoffs of an open system in terms of user engagement, creative input and real-world deployment.

1. Introduction

Interactions in the household define a complex and unpredictable microcosm. A wide variety of needs and appropriation possibilities, in fact, are ascribed to the heterogeneity of domestic activities and the ways in which inhabitants continually re-arrange and integrate informational artifacts to support their routines [1].

An approach that depends on dedicated devices and services would not fit with the highly dynamic context of domestic pervasive computing. First of all, the focus on specific forms of technologies, such as home automation, has had the tendency to disregard the variety and subtlety of domestic arrangements as daily experienced by inhabitants. In second place, work, leisure, communications, awareness, safety, health and wellness are not watertight compartments in people's domestic life. We do not want a different system for each of them, because dedicated apps will not scale and the potential of ubiquitous computing does not come from the capabilities of any single device. Instead, according to Mark Weiser, "it emerges from the interaction of all of them". Lastly, dedicated devices are not a sustainable choice: they will be discarded when the service they provide is no longer of use because they are unable to be recomposed and adapted to the needs of new situations.

New types of end-user toolkits (e.g., LittleBits[1] or Sense Mother[2]) have been recently launched in the market that provide a more human-centered tactic to support family interwoven and dynamic practices [2]. They focus on lowering the prerequisite technical knowledge and skills, thus empowering occupants to install and program networked sensors and actuators without the help of experts. End-user programming is a necessity more than a luxury for domestic computing [3][4]. Appropriations of smart technologies at home, in fact, afford a variety of use scenarios that cannot be anticipated at initial design time, since they capitalize on end-users' deep knowledge of the domestic space, the different activities that take place within the household, social conventions established among family members, and interpersonal relationships [5].

Inhabitants' changing needs can be quick and ephemeral or more permanent: from sharing a to-do list with other family members, or being warned when the kids are back from school or your elderly father has taken his medicine. Thus, domestic pervasive technologies should support those *serendipitous uses* that might exhibit a transient nature as well as a more habitual character. Technologies that evolve *along with use* and *together with the user* would allow to conveniently and timely re-configure the environment around their current necessities, whether they last for a year or just for a few moments, they are serious or trivial, or they are personal or shared.

In this paper, we investigate what it means to design an open-ended system that supports serendipitous uses and allows people to program domestic technologies by themselves. First, we report from a field study that shows

[1] http://littlebits.cc/kits/smart-home-kit
[2] https://sen.se/store/mother/

how users display unexploited potential creativity in using available pervasive technologies for their mutable routines. Second, we propose how to harness this creativity by a tangible programmable toolkit (T4Tags 2.0) that supports "if-trigger-then-action" programming (e.g., IFTTT.com) and is fueled by crowd-sustained appropriations of programmed artifacts. We furthermore provide insights from three workshops with different household to test the usefulness of sharing 'recipes' of programmed artifacts.

1.1. Supporting Real-Life Scenarios

T4Tags 2.0 provides small tangible tokens that embed different sensing technologies. Tokens can be easily attached/detached to physical objects in order to program smart behaviors for real-life scenarios and address heterogeneous needs such as: 'are my children home from school?' or 'I want to buy 100 capsules for my espresso machine', or 'has my father taken his medicine?'

We describe here the latter scenario to demonstrate the vision driving the design of T4Tags 2.0. A common issue with the elderly is the correct and timely administration of medication. Imagine that you want to know whether or not your father has taken his medicine on time. To this end, a token can be programmed by defining a "pouring" gesture. T4Tags 2.0 learns from the usage example enacted by the user, and allow to employ such new gesture as a trigger. The token can then be attached to the side of a medicine bottle (see Figure 3) to trigger the associated action any time someone is taking a pill. Both connected devices and token can act as a reminder through multimodal notifications. The user can enable these reminders and set triggers with time or motion, and potentially link the actions to a calendar, reminders or to-do list. Therefore, if my senior father takes his medication, I am notified with an email. Alternatively, the token can be programmed to send a reminder to both me and my father if the action has not been performed in due time.

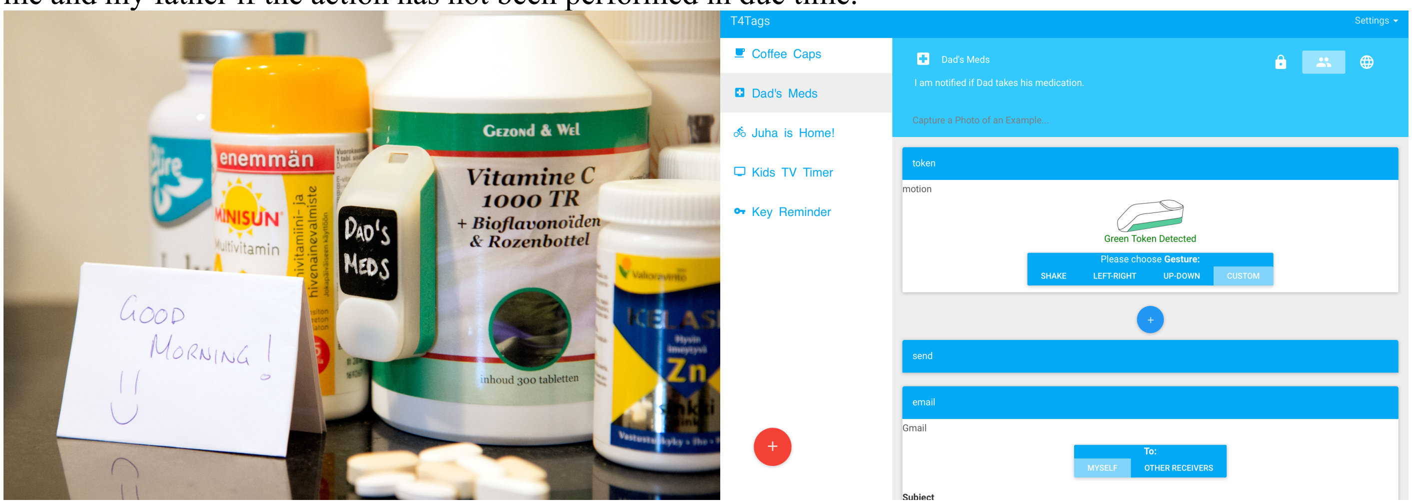

Figure 1. Left: A token attached to the medicine bottle. Right: A screenshot of the interface for implementing the scenario.

2. A Case Study Exploring Appropriations of Web-Connected Tags

We recently conducted field research on domestic appropriations of tangible tokens to web content that uncovered a plethora of scenarios and ideas of adoptions [6]. Those usages were not readily supported by simple implementations or laboratory prototypes, indicating the potential to pursue design of open-ended domestic technologies through in-situ deployment of a continuously evolving prototype. To this end, we adopted an approach of *prototyping with and by the user*, integrating Extreme Programming (XP) with co-design sessions as a tactic to quickly deploy a prototype that evolves as the result of repeated interactions with users. This allowed the designers to reflect on a variety of real-world usage scenarios as well as the users to learn from appropriations and to envision new uses. Briefly put, XP [7] is an unconventional development model that gives prominence to the availability of usable prototypes to accelerate the exploration of the design space through rapid cycles of software release. Its core principles of promoting iterative development, being customer-centered and scenario-driven squarely fit the critical demand of having a continuously working prototype always available.

We designed an initial concept of a domestic technology (T4Tags) that provided a toolbox for easily linking physical objects to web content via NFC. The prototype was intentionally left unfinished: during co-design sessions the designer would learn from situated use of the technology and decide, together with the users, the kind of functionality would be provided in new releases as a response to user's interactions. Our goal was to explore whether a system with undefined purposes, an abundance of design affordances and potentially many different usages would support existing routines at home. How would it be integrated into everyday practices and the existing landscape of heterogeneous artifacts?

Figure 2. Left: Components of the initial T4Tags design concept. Right: Components of the T4Tags 2.0 toolbox (smart power sockets, smart light bulbs, sensing tokens and wireless station and a tablet to program tokens behavior).

T4Tags (see Figure 2, left) consisted of a set of NFC stickers and 3D-printed physical tokens of different shapes and colors with embedded NFC tags. A WiFi-connected tray with an embedded NFC reader was used, in combination with a web interface, to edit the content of a token by adding or removing (drag-and-drop) web links. An Android native application allowed to interact with the physical tokens (e.g., to retrieve and display the content of the tag).

The initial prototype was deployed in a household (mother, father and two daughters of 9 and 12) and inscribed into a one-month design process that involved weekly co-design sessions alternating use, design and development. While co-design sessions gave a reflective account of various daily situations as articulated by participants, real-world deployment supported the generation of use scenarios at different times of the day and in private spaces that would not have been accessible during the co-design sessions. Participants were asked to record their interactions with the system in an online *diary*, documenting use with pictures and videos. The *diary* served as a communication artifact to support the dialogue between participants and researchers that weekly visited the deployment site to run the co-design sessions. To facilitate the analysis of usage try-outs, we created a template-based *journal* to document ideas, scenarios, use trials of scenarios without the need of new implementations, and use trials of new implemented features. The *journal* was intrinsically a working document meant to organize observations regarding successfully repeated usages, or abandonment after use or non-use of a feature. We then employed thematic analysis to organize the scenarios originated during the field trial and to identify themes for outlining the experience of our co-design process. More than developing a theoretical framework, we were interested in exploring people's lived experiences in the domestic context augmented with our technology [14].

2.1 Findings

While further details on the exploration of usage scenarios are provided in our previous work [6], we introduce here four high-level themes that manifested in the case study, which informed the design rationale for the next iteration of the toolkit.

F1. Foster creative power by readily evaluation. The fieldwork demonstrated that shaping the prototype during its use favored the experimentation and experiencing of complex usage scenarios and embodiments that informed the invention of new scenarios. While at the beginning the family considered only problems in their existing routines, the tag technology was appropriated in routines that served as inspirational sources for novel practices. The situated exploration of the scenarios and the usage try-outs during the co-design sessions allowed the family members to reflect on their own routines and also be inspired by other members' appropriations. The creative power of the users, therefore, was activated by self-reflection and quick evaluation of scenarios that allowed to draw inspiration from others. As an example, tokens were first envisioned as carriers of personal content: everyone in the family would have one token defined by color/form for personal use (e.g., storing personal data). This scenario inspired the development of other scenarios, such as using the token as a gift or for storing things to remember.

F2. Heterogeneity of use. NFC demonstrated to be a malleable technology that could be timely re-configured to support different models of use, from a vehicle for sharing information between family members, to a mean for supporting individual practices. Tokens were used or envisioned as a supporting technology for heterogeneous domestic activities, such as providing a link to media content, making information tangible, or logging in to applications. Their use exhibited an ephemeral as well as more enduring character. Their association with 'things to do', for instance, showed that tags supported transitory and quick activities and their content were temporary. Once the task was completed, in fact, the content of the token was cleared. In other cases, tokens afforded more long-lasting scenarios. Tokens, for instance were linked to media content to augment physical objects, kept as memories, given as a gift, or used as a password. The family articulated that the tag technology would be useful only if it would be easy to integrate with the ecology of physical artifacts they already use to store, manage and transmit information, such as calendars, to-do lists, notebooks or recipes.

F3. Need for programmability and customizability. Although the T4Tags system was open enough to allow the wide exploration of the design space for domestic NFC-based technology, it limited users' interaction to scenarios that involved some sort of content retrieval. Family members stressed that, to be really useful for their practices, the tagging technology *"would not only open links but would also have a function"*. The father, explicitly reported that tokens should be associated with some IFTTT.com-like capability, so that "*using a token would for example turn on the lights or update your Facebook profile"*. However, the scenarios collected during the study are only limitedly implementable through tools such as IFTTT.com because they miss composition of devices and end-user programming functionality beyond "if-trigger-then-action".

F4. Need for different trigger technologies. The need for programmability was accompanied by the demand to integrate different technologies in the household to support new appropriations. Tags were envisioned not only as a way to open content and convey information, but also to enable interactions with other smart appliances. For instance, the father would give a token to the children to turn on the TV only in a specific time frame. However, the design based on NFC technology fell short in supporting scenarios that are inscribed in the larger ecosystem of home appliances. The interaction with a token, in fact, was always triggered by the physical action of scanning the token itself with the mobile phone. More complex scenarios would have required the use of other triggers. Previous research [8][9] highlighted that in many situations smart behaviors are triggered by activities, locations, and states abstracted from physical sensors (e.g., motion, temperature, distance, etc.). For instance: "I want the sink to turn on when I pick up my toothbrush" [8].

3. Design Drivers for a Pervasive Toolkit for Serendipitous Uses

The fieldwork conducted in our previous research allowed us to reflect on the variety of usages that pervasive technologies might acquire in the domestic context, and to establish design drivers for the re-design of T4Tags as an open-ended system that supports such serendipitous praxis. We introduce the main principles that guided the re-design and connect them with the findings from the fieldwork. In the following section, we describe how these principles are addressed in the updated toolkit.

D1. Unfinished Technology: We want to provide a technology that does not have a pre-defined purpose, giving the users the possibility to re-purpose and complete it as a result of their situated continuous experience and needs. The technology is intentionally left unfinished in its purpose and partially unconstrained to spur end-users' creativity in the actual use of an artifact [10]. Unfinished technologies potentially support multiple usages and meanings (F2), foster proactive users' behaviors and discovery-driven materialization of new ideas (F1), increase spontaneous participation and engage with creative power (F1), and support users' customization (F3).

D2. End-User Programming: We want to enable users to design and program by themselves the trigger-based behaviors of sensors and actuators as well as the physical configuration of the technology in the domestic space. In today's increasingly complex technological landscape, it is critical to give people the tools to actually solve their own problems by themselves. End-User Programming [11] provides methods and tools (e.g., programming-by-demonstration) to support active users' participation in the development of interactive systems considering natural behaviors of end-users and the situational use of technology. It upholds the needs for advanced programmability of domestic technologies by non-programmers (F3) and the easy integration and re-combination of different sensing technologies (F4), which in turn support the quick composition of hardware/software building blocks for heterogeneous uses (F2).

D3. Crowd-fueled Sustained Appropriation: We want to exploit the creative power of the crowd by letting users sharing their 'hacks' for domestic life. This could help people identifying if there are solutions created by others that can suit their needs and their current situations (F1). As experienced in our fieldwork, scenarios envisioned by one family member served as inspiration for others, thus generating a chain-reaction exploration of ideas that led to the creation of new appropriations [6]. Online crowdsourcing tools can be used to emulate this behavior, thus exploiting users' routines as an inspiring source for creating new smart home features on a wider scale, with the goal of scaling up our toolkit to reach different households.

D4. Hardware Versatility: We want to design sensors that can be easily integrated with the ecosystem of existing artifacts at home to easily craft smart objects. They can be attachable/detachable to accommodate quick and heterogeneous uses (F2), and provide different sensing technologies (F4). Sensors that can check environmental information (e.g., light, temperature or motion) can be used as triggers to program advanced smart home functionality (F3). Augmenting existing objects with sensing capabilities could leverage their affordances to benefit from user interaction with the physical world: manipulation of visible artifacts facilitates situated learning and epistemic actions (F1) and promote the implementation of end-user programming features, such as programming-by-demonstration powered by direct interaction with real objects (F3).

4. The T4Tags 2.0 Toolkit

We developed T4Tags 2.0 as a toolbox that comprises (Figure 2, right):

- A set of 3D-printed Bluetooth-enabled physical tokens that embeds different sensing technologies: NFC, motion, light and temperature sensors, and a physical button;
- Two Bluetooth Low Energy (BLE) programmable light bulbs;
- Two BLE programmable power outlets;
- A wireless station, coupled with a web, mobile-oriented application that provides a ubiquitous entry point to manage sensors, smart bulbs and power sockets.
- A tablet for programming smart behaviors through the web application.

Hardware. The station encloses a Raspberry PI device with WiFi, BLE, and a NFC reader card (NXP Explore-NFC). The tokens' hardware is build around the LightBlue Bean[3], a BLE Arduino microcontroller that can be programmed wirelessly, runs on a coin cell battery, and offers a small and versatile platform for sensor-based projects. The device features a 3-axis accelerometer, a temperature sensor, a RGB led, 6 digital I/O pins, two

[3] https://punchthrough.com/bean/

analog pins, and an integrated soldering board that made it easy to extend its functionality by adding a light sensor and a physical push button (D4). Custom, Bluetooth-enabled smart power outlets and light bulbs are provided in the toolkit to implement interactions with other electrical appliances in the home.
Software. T4Tags 2.0 supports the end-user programmability of tokens through an adaptive web app (D2). It allows users to compose, edit and share instructions that define the behavior of a programmed token (D1). Such *recipes* add to other trigger-based systems (e.g., IFTTT.com) the possibility to compose *conditions* that define triggering constraints by linking different events with conditional operators. Predefined triggering events are provided and custom events can be defined through tangible interaction with a programming-by-demonstration approach [11], in which the system learns new triggers by 'watching' the user performing/demonstrating them (e.g., motion gestures). Predefined gestures are provided, such as "shake", "swipe", and "up-down". Since the tokens did not fully support the functionality for programming motion gestures by example, user-defined gestures were simulated during the evaluation. T4Tags 2.0 also provides crowdsourcing tools to share implemented recipes (D4). The interface for generating new recipes allows to include pictures describing user intentions and sensor placement, in order to instruct others how to adopt the recipe.

5. User Study: Workshops with Families

To test the usefulness of the system and the recipe sharing functionality we conducted three half-day workshops in three different households in the Helsinki area, Finland. The first workshop explored the applicability of T4Tags 2.0 to support users' needs in the domestic environment, and aimed at populating the library of available recipes to be used in the following workshops. The goal of the successive two workshops, in fact, was to investigate whether the recipe sharing functionality effectively supports users in the programming tasks and fosters their creativity.

The three families consist of young couples (their age ranged from 37 to 41) with children: two daughters (7 and 4 years old) and one son (2) for the first family, two sons (7 and 9) for the second, and two daughters (7 and 9) for the third. The parents are keen to the use of technology at home (e.g., Netflix and tablets to watch cartoons and series), but none of the families owns a smart home toolkit.

5.1. Procedure

After deploying the toolkit in the household, its main functionality was introduced by showing an example of how a recipe can be created with the mobile interface, e.g., send an email when pressing the button of a token (15 minutes). Then, a creativity warm-up (10 minutes) took place to stimulate family members' imagination for the brainstorming session that followed. During the brainstorming (1 hour), each family came up with different ideas and scenarios for T4Tags 2.0: some of them could not be implemented and were enacted, while others were implemented in a subsequent session to evaluate the usefulness of the toolkit. To implement the ideas, each family was given a tablet to interact with the mobile app (see Figure 1, right). For the second and third family, the recipe library contained 11 recipes generated by the first family, which they could adopt or take inspiration from.

After the implementation phase (2 hours), all the three workshops ended with a brief interview (30 minutes), to gather information about parents' experience with the system. All the phases of the workshop, including the brainstorming session and the interview, were done in English and video recorded.

5.2. Results

We were able to collect and document a total of 111 ideas from the three brainstorming sessions (30, 41 and 40) that resulted in 101 unique scenarios, 60 of which were implementable. This confirms our findings from earlier informing work (F2) and the derived design drivers (D1, D4) that users would combine triggers and actions in a wide variety of ways. Thus, they need a high degree of programmability/customizability (F3) as addressed by the end-user programming features of our toolkit (D2). The most common triggers were related to occupancy or presence in a room (27 of envisioned scenarios), time (25), location (19), and environmental sensing such as temperature or light (16). Fifteen triggers implicated the detection of motion (e.g., inferred by an accelerometer), such as opening a door or picking up an object. Common actions were notifications/reminders (34), control lights (16), control domestic appliances, such as television sets, heating or ventilation (33).

Scenarios that could not be implemented (18 out of 41) involved programming domestic appliances (e.g., prepare the coffee at 7.30 am), which would require specialized hardware functionality or hacking existing hardware and therefore they were too far-fetched and not suitable for end-users repurposability. Six other scenarios required precise location data (the toolkit can only check the BLE distance of tokens from the base station) and 17 would involve sensors not included in the current toolkit (e.g., moisture).

During the workshops, participants implemented 26 scenarios (out of 60) they considered useful and that could make their life easier. Eleven were implemented from scratch by the first family. The second and third family implemented 15 scenarios: 4 of them were adopted/tailored from existing recipes. Overall the families could easily implement the desired scenarios without any help from the researchers: some of the scenarios were implemented by older children (e.g., in the first workshop the 7-years old daughter implemented by herself a recipe to open a Youtube video using the integrated NFC tag as trigger). Scenarios ranged from turning on/off the light or the WiFi router at a specific time, keeping track of the time children spend playing an instrument or "remind me to take the keys when opening the door to go out."

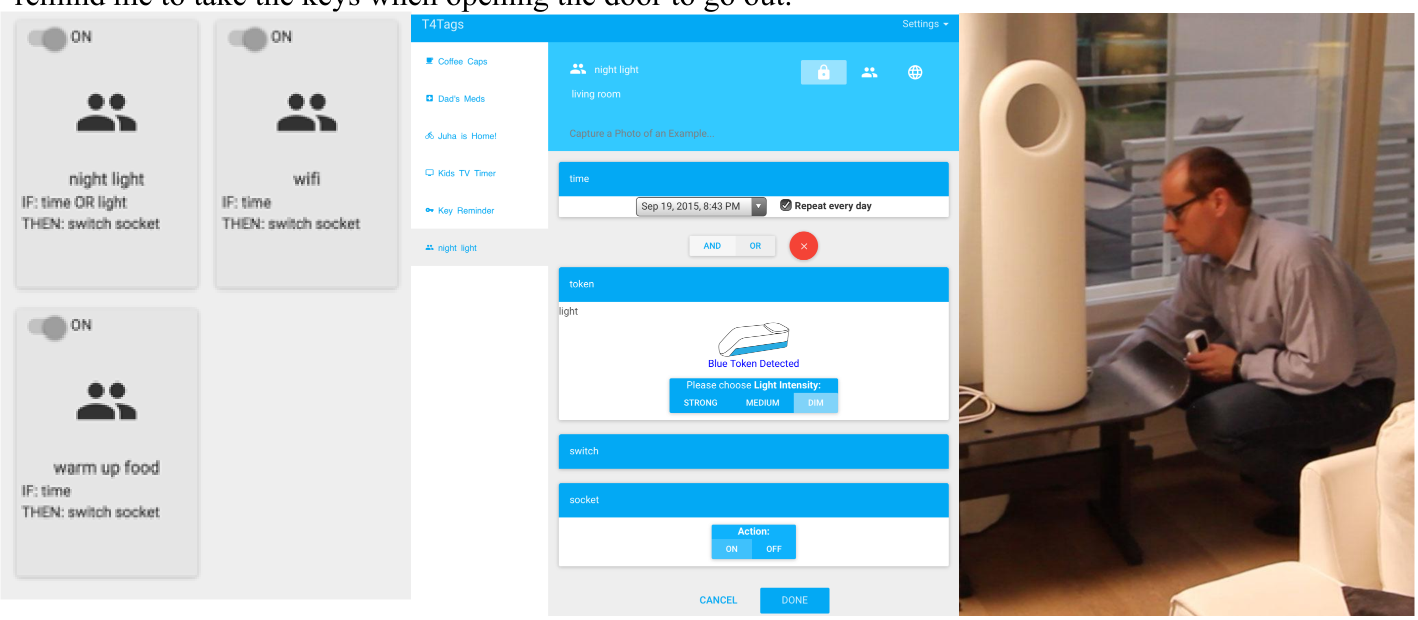

Figure 3. Left: The list of available recipes. Center: The user interface to tailor the recipe. Right: the father plugging the desk lamp to the smart power outlet.

We show with an example from the workshops how users can adopt a recipe to program smart behaviors. The second family wanted to turn on automatically one of the desk lamps in the living room at a specific time (8.43 pm) or in case the light was dim (see Figure 3). They thoroughly inspected the list of available recipes. They trusted that, since people have similar habits, they would have found some recipes for not starting programming from scratch. Indeed, the first family has had a similar need and a recipe was already available in the library that the second family was able to customize. For instance, they could change the daytime and also add a conditional rule to check for the light condition in the living room (Figure 3, center). The recipe also provided images and a textual description of the required hardware (e.g., a power outlet) so that the family could easily select the components and install them in the living room.

6. Discussion: Opportunities and Challenges

Our experiences with the fieldwork and the evolution of the T4Tags platform revealed opportunities and challenges for the development of serendipitous technologies.

Designing for ephemeral uses. An approach that exploits incompleteness as a design strategy and provides room for the end-user to participate could be a solution to build technologies that need quick means to be used and reconfigured. A successful tool, therefore, needs to support users in composing meaningful and complex interactions, which means that it has to expose functionality to empower end-users to materialize the experience of their everyday actions and needs into technical features. Simple trigger-action programming like the one afforded by IFTTT.com that relies on basic rules, is not enough to program smart behaviors. Even if many actions in the smart home can be expressed as a result of a single trigger event ---turn on the light at 8.43 pm---, desired behaviors are often the consequence of more complex interactions that require the composition of more than one trigger or action ---turn on the light at 8.43 pm or the light is dim. This requires to extend the trigger-action format to include conditional operators and constraints. Indeed, the evaluation showed that users were able to easily compose and implement rules for such behaviors. Successful applications need also to provide different programming alternatives, such as tangible approaches that allow to programming sensors by physical demonstration. During the workshops, participants exploited real-world tangibility ---that's it, the possibility to augment and interact with real object--- as a way to envision and implement new routines, e.g., "tell me when my daughter took the guitar and if she is playing it".

Continuously Renewed User Engagement. Designers need to reflect on the tradeoffs of an open technology that, from the one side, provides flexible control to support changing needs but, from the other side, it heavily relies on users' proactive participation, motivation, engagement and creative input. Crowd-pulled development could be a solution for a sustained user engagement since our fieldwork has found that users are curious to see how other people use technologies in their homes [6]. We have learned that the benefit of a crowd-enabled sharing of technology usages can be twofold: (1) people can discover what technology can do for others with similar interests or households that are similar to their own, which allows users without programming experience to be able to create new configurations easily, (2) users could observe how others customize their original recipes and establish a "crowdsourced fine-tuning" mechanism (as one of the participants called it), in which they can learn new ways to adapt/evolve existing recipes from the crowd.

A possible challenge concerns how to overcome privacy issues as perceived by users. Even if participants praised the presence of recipes both as inspirational artifacts as well as for speeding up programming, they were reluctant in publicly sharing their recipes. In fact, when creating or tailoring existing recipes, they always chose a "private", or "family" visibility. When asked, they said that they " [...] would not be comfortable to publicly share their own private routines". Successful designs for crowd-based functionality should provide mechanisms to encourage users actively participation (e.g., rewards). Nonetheless, cultural inclinations can play a big role here and further investigation is needed to understand perceived privacy threats involved in publicly sharing recipes.

Learn from "the wild". Systems that aim at supporting people in their household activities cannot be evaluated in the vacuum of the laboratory. A current challenge, therefore, focuses on how to deploy those technologies "in the wild", thus assessing if they address inhabitants' high-level goals and are suitable for everyday use. Indeed, our current approach allowed to evaluate the usefulness and the effects of the proposed technology in an ecologically valid life-settings. However, our study ---as well as the ones from the literature [12]--- is short in time and addresses a limited number of households. Longitudinal studies are needed to better understand long-term usage once the system's novelty wears off and gain insights that are more representative of the normal use of the technology.

In our experience, finding a large sample of families that are willing to participate to long-term studies constitutes a serious hindrance to the experimentation. The domestic environment is a sensitive setting and many times inhabitants perceive the presence of the researchers that install the system as a threat to their privacy. The same holds true for co-design or follow-up sessions we run to collect information and to keep them engaged in using the technology [6]. We therefore identified the need of a tactic to reach a wide sample of users while maintaining a cost-effective and scalable approach. Research in the large [13] could represent a solution for “in the wild” studies of domestic technologies, since it proposes a modus operandi that relies on app stores, markets and other wide channels for the distribution of applications with the goal of reaching a world-scale sample. T4Tags 2.0 has been designed as a do-it-yourself, ready-to-work toolkit that families can order from a website, receive at their home and install by themselves. This tactic would allow to reach more households, thus mitigating the effort of ‘recruiting’ an appropriate mix of users. At the same time, it would allow to collect large amount of data, which would be impractical for limited deployments. Moreover, it would create a more realistic setting for a future a long-term evaluation. In such a wide and open context, in fact, users could decide to stop using the technology for any reason (and we could learn from that), and not just because the experiment ended.

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