Designing IoT Systems that Support Reflective Thinking: *A Relational Approach*

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Systems are, to a large extent, about relationships between people, activities, objects, technologies, and places. A systems approach focuses on how things are interrelated, and what the different parts can accomplish together. In similar terms, reflective thinking is also relational. We think often with each other when we talk about and share our experiences and memories. We are also increasingly using smart objects for our everyday activities. However, designing IoT (Internet of Things) devices typically relies on artifacts rather than relationships. In this paper, we present a modeling technique for the design and analysis of IoT artifacts and systems that is fundamentally relational in its approach. Having outlined the need for relational approaches to designing IoT systems, we first present three examples, where we demonstrate how our relational approach allows for the analysis of existing smart objects designed to function in different relationships with the user, user activity and the situation. Accordingly, we present these IoT systems from the perspectives of the *augment me*, the *comply with me*, and the *engage me* relational models. Having presented these three examples that illustrate how IoT systems can be analyzed as systems of relationships, we then present the prototype of an IoT artifact intended to support reflection in the user. With this fourth example, we introduce the *make me think* relationship, and also show how our modeling technique can be useful for design of new IoT systems.

Accordingly, we suggest a modeling technique that can be used as a tool for designing and analyzing IoT systems. We believe this modeling technique can contribute to a relational approach toward IoT. We conclude this paper suggesting that our proposed modeling technique cannot only help to model relationships between a user and a smart object, but can also be scaled, allowing for the modeling of more complex IoT systems, where there are an increased number of users using many smart objects in different places, but still integrated as a complex system.

Keywords **–** IoT System, Design, Modeling, Reflection, Relationships, Smart Object.

Relevance to Design Practice **–** This paper offers a relational approach to the modeling of IoT systems. This approach allows for the analysis of the relationships between the components that constitute IoT systems. In doing so, we suggest a modeling technique in order to support both the analysis and design of IoT systems. This could be as a support for industrial and interaction designers, not only for shaping a particular kind of relationship, but also for designing physical artifacts that can support that kind of relationship.

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Introduction

It has been predicted by many scholars that we will be increasingly surrounded by autonomous, computational, and interactive artifacts (e.g., Weiser 1991; Zuboff, 1984). Not only do these smart objects increasingly surround us, but we also experience different relationships with different devices, and in relation to different interactive systems. For instance, we *use* a calculator as a *tool* to carry out mathematics, we *blend with* step counters to *motivate* us to take more steps, and we *install* a smart thermostat and *let it* regulate the temperature in our homes. In short, we have different *relationships* with different smart, computer-based artifacts. Each relationship suggests not only how we will interact with an artifact, but also what it can do for us, and how different things serve different purposes that, when taken together, make our lives easier. Some have referred to this trend in terms of the emergence of *artifact ecologies* or *the new ecology of things* (e.g., Allen, 2007; Jenkins, 2015; Robbins, Giaccardi, & Karana, 2016), *interaction landscapes* (Wiberg, 2012; Wiberg & Zaslavsky, 2010), or simply *interactive systems* and *interactivity fields* (Janlert & Stolterman, 2016, 2017).

The modeling of these different ways through which we relate to these systems of smart things is the main focus of this article. We suggest using these models not only as a generative tool

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aiding the design of such artifacts, but also as an analytical tool to study existing ones. Although it has been often acknowledged that an IoT device works in a system of things, places and people, the design of such systems often followed a traditional approach, wherein the single device is considered the final product (e.g., Hornecker & Buur 2006; Kortuem, Kowsar, & Fitton, 2010).

However, while this traditional product design approach allows a focus on the properties and the overall functionality of a single artifact, it is limited for the design of bigger, interconnected and more complex interactive systems. The systems approach, on the other hand, could become too complex, broad and hard to manage, meaning the outcome of design process remains undefined and continuous. As a contribution to this challenge, we propose a *relational approach* to the design and analysis of IoT artifacts and systems. Although this approach aims at designing a concrete artifact as the outcome of design process, it takes a broader stance by defining artifacts' functionalities, behaviors and forms, based on a particular relationship. In this regard, the relationship becomes the purpose and also the intention of designing the artifact.

The interest in designing for reflective thinking in the human-computer interaction (HCI) and design communities is growing, especially with the purpose of behavior changes in user. However, there are few examples in literature that describe attempts to create guidelines and theories for the design of such systems. Fleck (2012) and Fleck and Fitzpatrick (2010), for instance, provided a framework summarizing the literature outside of the HCI field about reflection. They included in their framework three important aspects of reflection, namely purpose, condition and levels of reflection and then they listed technologies that could support reflection. In a more specific way, Baumer et al. (2014) saw reflection as an alternative to traditional and persuasive ways of behavior change, especially for sustainable behaviors.

As a contribution to this challenge, we suggest considering *reflective thinking* (reflection) as a user activity and reference task (Whittaker, Terveen, & Nardi, 2000). We believe it can help build a common ground for projects focusing on designing IoT artifacts that support reflection for a variety of purposes. Despite, in this paper, particularly the purpose for reflection is behavior change in the area of sustainable urban mobility behaviors.

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Reflective Thinking

Reflective thinking as a distributed cognitive process is not only individual, but also relies on external stimuli and activities, such as materials, situations, talking with other people and writing (e.g., Hutchins, 1995; Norman, 1993; Papert, 1980; Rogers, 1997; Salomon, 1993; Schön, 1983, 1992; Turkle, 2011). Of those external stimuli, physical objects and especially computing artifacts play a crucial role (Papert, 1980). John Dewey (1933), in his seminal work "How We Think", described how reflection is a deep consideration of experiences and actions, in order to discover connections–i.e., relationships. He further pointed out that experiences are consequences of interactions between oneself and others–people, artificial and the natural worlds. Reflection is a systematic, rigorous and disciplined way of thinking. It is a meaning-making process through which people move from one experience to the next with a deeper understanding of its relationships and connections. Reflection does not involve simply a sequence of ideas, but a consequence of ideas as Dewey (1933) stated: "… is a consecutive ordering in such a way that each determines the next as its proper outcome, while each in turn leans back on its predecessors" (p. 4).

Later thoughts grow out of, and support, the earlier ones. This chain or thread of thoughts is not only an individual process, but it also involves other entities, such as other people, objects, activities and places. These entities are the components of the system and are connected to each other through relationships.

In addition, Rodgers (2002) outlines: "Reflection needs attitudes that value the personal and intellectual growth of oneself and of others" (p. 845). Furthermore, in cognitive science, it has been defined both as a top-down and also conceptually driven cognitive process. It means, reflective thinking relies on either external stimuli and internal beliefs and concepts (Norman, 1993).

In short, we are interested in systems of smart and interconnected objects and how such systems support reflective thinking through relationships. Furthermore, if reflection is relational, and if we set out to design smart artifacts that support reflection, we need a modeling technique that enables us to study those relationships. One that goes beyond the study of *interaction* between computing artifacts and people and considers, instead, the *relationships* as the purpose for design. In this endeavor, we are inspired by Alex Taylor's *After Interaction*, in which he stated that interaction as a concept contributes to separation rather than connections and relationships (Taylor, 2015). Since the concept of interaction deliberately makes a clear division between people, computing artifacts and environments, it cannot be suitable for studying the systems of computing artifacts such as the Internet of Things (IoT).

We need an approach to view computing artifacts in relation to their user and to their physical and cultural context, not as stand-alone products, so we can focus on the purpose of that relationship. This paper is an attempt to contribute to one such approach.

Our proposed modeling technique seeks to open up the analysis of existing IoT systems as well as supporting the modeling of new ones. To this end, we examine the relationships for three examples of computing artifact categories and create a model for each. For each model, we consider the relationships between the user, the artifact, the situation, and the user's activity. Hence, we provide examples of those relationships, namely: 1) ***augment me***; 2) ***comply with me,*** and 3) ***engage me***. As we will illustrate with the models, these three examples demonstrate a range of different relationships with computing and smart artifacts, which are essential to learn from in order to model the fourth model capturing the ***make me think*** relationship. Accordingly, we explore, reflection on an activity as a user task and how smart artifacts in an IoT system can support it. We model the ***make me think*** relationship by analyzing a prototype and its characteristics from an early demonstration of our concept (Lim, Stolterman, & Tenenberg, 2008).

We will describe in this paper how interactive artifacts enable different relationships for augmentation, compliance, engagement and reflection. We suggest that prior to thinking about designing systems of IoT artifacts, we need first to understand how to design *different relationships*, as systems are, to a large extent, about relationships or forces that connect the parts and make sense of a system as a whole (e.g., Banathy, 1996; Bertalanffy, 1968; Churchman, 1972).

We examine reflection as a reference task, reflect on our own methodology and technique of modeling through analysis of the prototype, then conclude the paper with implications for interaction design theory and practice.

Modeling IoT Systems: *A Relational Approach*[1]

We create relationships with artifacts by sensing and using them during activities (Bødker, 1989; Vardouli, 2015). Furthermore, as Turkle (2011) suggested, we need to move beyond considering artifacts as just useful or aesthetic, and also try to consider them as companions to our emotional lives or as thought-provoking devices. Seeing artifacts as just being useful originates from using computers in the work environment and from when the notions of *interface* and, consequently, *interaction* were introduced (e.g. Bannon & Bødker, 1991; Norman, 1988; Janlert & Stolterman 2016). The artifacts relate also to their surroundings and with human activity. For instance, as Bødker (1989, 1991) stated, a computing artifact–a user interface–cannot be seen independently of its use, and an artifact is actually defined by its user and the nature of the activity. These relationships are influenced by not only social, cultural and environmental conditions, but also by the artifact's features. Indeed, the artifact's physical characteristics seem to be crucial in shaping and influencing user activity and behavior. This has been long debated in the behavior change design arena, for example Lockton et al.'s (2010) Design with Intent, or the concept of artifacts' affordances that can shape and guide the way an artifact can be used (Norman, 1988, 2013).

The application of the Activity Theory framework in Interaction Design also suggests that the user forms an activity-oriented relationship with the artifact (Kaptelinin & Nardi, 2006). Activity in this framework is a purposeful action towards accomplishing a specific user's functional goal by using an artifact. Furthermore, the reference task agenda suggests there should be a focus on a specific user task and an investigation into the ways the computing artifact can support that task (Whittaker et al., 2000). Therefore, for the design of IoT artifacts and systems, a key factor is to understand these activity-oriented relationships.

For the design community, this is not new: design has always been about manifesting and guiding such relationships in artifacts. Interaction design, for instance, is about the design of various computing artifacts which do not appear as an isolated artifact but interact with users and the environment, accordingly making different relationships between them (Dix, 2009; Preece, Rogers, & Sharp 2002; Verplank, 2009). In addition, in the HCI domain, those relationships have been suggested to be designed purposefully to support a very specific user task or activity (Kaptelinin & Nardi, 2006; Whittaker et al., 2000). On the other hand, in a traditional Industrial Design process, a user's activity to achieve a functional goal has been a crucial factor in defining the artifact's functions, forms, and behaviors. Therefore, the user's activity, the use, the artifact's characteristics, and aesthetic and cultural values all determine the relationship between the user and the artifact (e.g., Janlert & Stolterman 1997; Crilly, Good, Matravers, & Clarkson, 2008; Gero & Kannengiesser, 2003).

With physical artifacts, the physical and sensory properties—e.g., forms, colors, and texture—influence the user's activity during interaction, whereas with digital artifacts—e.g., websites and mobile apps—the representation of the information on the user interface plays the most important role (e.g., Norman, 2013). Hence, artifacts can shape our mind, influence our behavior, activity, and our way of thinking (Malafouris, 2008; Salomon, 1993; Turkle, 2011). Accordingly, we believe we need a better understanding of such relationships in order to design better systems that support reflection. To this end, we first explore three different relationships, then determine the properties of the ***make me think*** relationship from analysis of a prototype to produce a model.

So, we will first present three examples of relationships with computing artifacts and how they can be related to a user's tas, goal and the situation. We will do this in order to lay the groundwork for: 1) introducing the model of ***make me think***, 2) presenting the properties of the computing artifact able to evoke reflection, considering different interactions with the user, other artifacts and the environment.

Understanding The "Augment Me" Relationship

One of the oldest relationships that users have formed with computers is the one that we refer to as the *augment me* relationship. In this kind of relationship, the user and the computing artifact exist in an equal and balanced collaboration. This relationship requires input from the user with the computer providing outputs in the form of perceptible feedbacks. These flows of inputs and outputs assist the user in achieving a functional goal. For instance, the early computers were simple calculators, designed to augment their user's capabilities to solve mathematical problems faster, and in a more efficient way.

In this relationship, the user provides the problem in the form of inputs to the computer, which consequently completes the task of solving a mathematic problem, and provides outputs as solutions. Considering that users need to have at least some basic knowledge about mathematical operations—i.e., multiplying, addition, subtraction, etc.—in order to carry out the task with a calculator, it is not just the computer that does the work, it is the result of a balanced collaboration with the user. Another important characteristic of this relationship is that the user has overall control, because the calculator provides a very narrow range of control and operations (Janlert & Stolterman, 2017).

Thus, in summary, the most important characteristics of the ***augment me*** relationship are 1) balanced collaboration between user and the artifact, 2) there is always a specific task to be undertaken in relation to the artifact, and 3) the user has overall control of this relationship—a calculator is usable only when a user turns it on, or in the case of software calculators, when a user opens the application or program. The user knows exactly when a calculator is working or when it is on, and for what particular task it will be used.

As is illustrated in Figure 1, ***augment me*** is a direct relationship between a user and an artifact—the dotted line shows the boundary and actors involved in the relationship. So, first the user and the artifact make this relationship (1.) and then the task is completed (2.), as a result of this relationship.

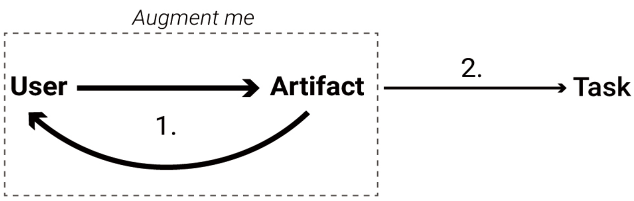

Figure 1. Augment me relationship model.
(The numbers show how this relationship unfolds.)

This is a simple, unequivocal and direct relationship between a user and the computing artifact, which consequently creates a one-to-one conversation between actors. The actors of this relationship, their intentions and the task are substantially, and in a transparent way, known to either participant.

If one considers a different situation in which the user and the artifact are not in an equal and collaborative relationship, where they do not actually create a one-to-one conversation with each other in order to carry out a task, and where the artifact is not just controlled by the user but also by other sources of inputs/information to which it is connected, how can we then call this a relationship? This situation is the one we actually face when we seek to understand the nature of the relationship between an IoT artifact and the user. So, if we consider a computing, smart connected artifact, which has multiple sources of inputs other than just user inputs—such as an IoT device, which is an artifact that can receive/send data from/to multiple parties—is there any real relationship between user and artifact? How can we describe and interpret it?

Understanding The "Comply with Me" Relationship

When computers became faster, ubiquitous, artificially intelligent and also connected to the Internet, they became capable of carrying out more complex tasks, some autonomously. In other words, users were no longer required to participate in some tasks, and could let the computer do the tasks for them. This could lead to a new kind of relationship between users and computing artifacts, the ***comply with me*** relationship. In this relationship, the user undertakes a few simple steps prior to running the artifact, such as adjusting and installing the device, and then the device itself carries out the task for the user. In this context, the relationship is focused mostly on the computing artifact and the situation, which includes all the different information and input sources, such as other smart artifacts, both local and remote. Therefore, as we can see, there is no actual and direct relationship with the user in order to carry out a task. The relationship between user and the artifact is formed around the way in which the artifact provides feedback through showing the status of the system. The types of feedback provided to the user can vary. They can be in the form of sound notifications, text messages or graphical representations, which aim to provide real-time information about the status of the system or alert (e.g., the nest thermostat displays the texts: learning, cooling, away or gives graphical representations such as the green leaf when a user is saving energy).

For instance, the relationship between the user and the *nest*™ thermostat is a ***comply with me*** relationship. The nest is a smart thermostat, connected to the Internet. Its embedded sensors and algorithms learn the user's central heating usage and it will adjust itself automatically in order to maintain the user's thermal comfort. It is also connected to cloud services, receiving real-time data from different sources, for instance from local weather channels, in order to adjust the indoor temperature in relation to the outdoor temperature. It can also be remotely controlled using a mobile app. As a result of these relationships between the *nest* and the situation—other elements and artifacts that nest is connected to through Internet connectivity—*nest*™ is able to satisfy its user comforts. In this context, adjusting the temperature, for example, is the task and maintaining thermal comfort is the purpose of that task. This kind of relationship differs from the ***augment me*** one in the way the user is involved in the task. In ***comply with me***, user let the artifact do the task, there is not an actual balanced collaboration between the user and the artifact nor a direct conversation between them, the artifact complies with its user. To do so, the *nest*™ thermostat is in conversation with many other sources of input, a scenario we refer to as situation (Figure 2). The thermostat does not require any human intervention to carry out the task and it is almost invisible, working silently in the background, and requiring very little cognitive effort by its user.

In contrast to the nest, which is designed to do a very specific task—adjusting the temperature—Amazon *Alexa* devices present another example that forms a ***comply with me*** relationship, but is able to carry out multiple tasks for its user. An Amazon *Alexa* device is a home-based artificial intelligence, a conversational agent, without any particular user interface or surface with which a user may interact (Janlert & Stolterman, 2014). Hence, it seems that it has been designed without one particular task in mind but for a series of tasks.

The ***comply with me*** relationship is shown in the Figure 2. The artifact first connects to the situation, which includes the whole system of other actors and information sources connected to each other. Consequently, the artifact does the task or tasks and then sends the status information to the user.

To summarize, there appears to be three relevant characteristics of the ***comply with me*** relationship. The first is the absence of a balanced collaboration between user and the artifact in order to carry out a task. The user usually gives orders without sufficient knowledge about the ways a task can be achieved, and the artifact complies and carries out the task for the user, receiving information from the situation. Second, depending on the designer's intentions and the artifact's functionality, it could be one or many tasks that the artifact can undertake, complying with the user. Third, the user may not have complete control of this relationship, since this is not a one-to-one conversation, so the user is not the only actor that provides inputs in the form of information. As illustrated in Figure 2, in the ***comply with me*** relationship, an artifact primarily relates to the situation and so its relationship with the user is secondary. The dotted line shows the underlying components involved in the relationship. So, in this relationship, first the artifact connects to the situation, which comprises the environment and also other smart objects (1.), and then the task is completed and it provides textual, aural or visual feedbacks for the user (2.).

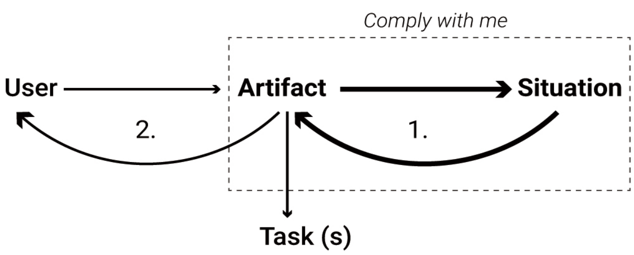

Figure 2. Comply with me relationship model.
(The numbers show how this relationship unfolds.)

What about wearable technologies? They are designed to be put on, always connected and in touch with the user's body, and are free of any specific physical context. What kind of relationships can they create with their user?

Understanding The "Engage Me" Relationship

Wearable technology has led to having small connected computers everywhere all the time. They are usually designed in a way that can be easily worn and be in touch with our bodies. They can collect, analyze, and recall data when needed. Personal data are collected by such devices using built-in sensors and Internet connectivity. The information can then be recalled and used to inform users about their actions and activities. The act of being informed about aspects of personal life (e.g., moods, performance, food consumption, etc.) through self-tracking technology has been termed the quantified self, lifelogging or personal informatics (e.g., Braber, 2016; Li, Dey, & Forlizzi, 2011; Pousman & Stasko, 2006). This process of collecting and storing data and then building knowledge from it, in order to provide feedback to users, has been proved to make users reflect on their actions and personal aspects of their lives. Feedback is provided through a user interface (UI) and, in almost all cases, through videos, photos or data visualizations techniques on screens (e.g., Gašević, Mirriahi, & Dawson, 2014; Houben et al., 2016; Kefalidou et al., 2014; Young et al., 2015).

The relationship here between user, user's data and user's personal goal is what we call an ***engage me*** relationship (Figure 3). This is the most complex relationship in comparison to the previous ones because it involves the three components of the relationship simultaneously, so the user, the user's personal data and the user's personal goal. For instance, Fitbit is a wearable, is a smart bracelet and an activity tracker that tracks user activities, collects data and then provides feedback about, for instance, how many steps have been taken, how many calories have been burned, the user's heart rate and so on. It also supports and motivates users to achieve their predefined goals (Purta et al., 2016). In this kind of relationship, a personal goal is the user's motivation to undertake a task but it can also change the task—i.e., running faster or slower—as the artifact is engaged by the user and also engages the user when carrying out that activity.

Thus, the ***engage me*** relationship has the following fundamental characteristics: 1) the primary relationship is between a user, user's data and her/his personal goal, 2) the artifact is not actually used in order to carry out the task—a bracelet is not used by user in order to run—3) the artifact is used when carrying out the task, 4) there is no specific place or time for using the artifact.

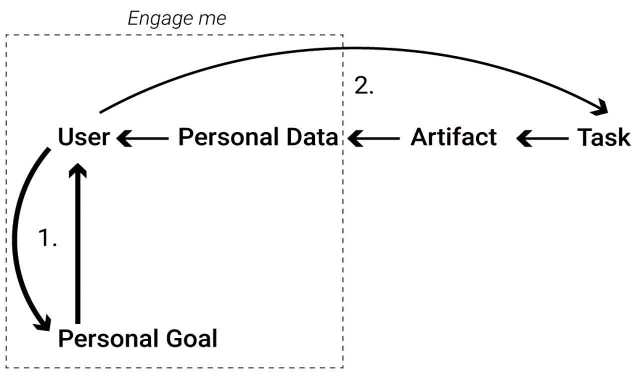

Figure 3. Engage me relationship model.
(The numbers show how this relationship unfolds.)

These models are basic and simple, with few essential components, but we believe we can analyze more complex IoT systems, with more users and artifacts using the same modeling technique (Brown, Bødker, & Höök, 2017).

So, given the analysis of models regarding the way a computing artifact relates to the user and to other components of the system, we can now think about the relationships that the user creates with an IoT system in order to support reflection as a very specific but relational task.

Designing IoT System for Reflection: *"Make Me think" Relationship*

The idea of using computing artifacts as tools for enhancing the learning process, creativity and especially for aiding reflective thinking is not new. In particular, designing the features of a computing and interactive artifact in a way that can foster thinking and cognitive development has been the subject of much research in the fields of cognitive and learning science. For instance, Pea's (1985) concept of *cognitive technology* is one of the early examples of concepts for designing such artifacts. This concept involves using computing technology as: "mediums [tools] that help transcend the limitation of mind, such as memory, in activities of thinking, learning and problem solving" (pp. 168). Cognitive or mind tools promote learning and thinking *with*, instead of *through*, computers, enabling learning *with* interactive technology as an intellectual and active partner. They are designed and adapted to the learner's environment in order to engage deep reflective thinking and a higher order of critical and meaningful learning. This engagement also helps learners to generate ideas in the context of problem solving (Lajoie & Derry, 1993; Jonassen & Reeves, 1996).

To summarize, it has been suggested that various interactive technologies seem to be effective in learning and thinking, either *through* and/or *with* them. In this regard, learning *with* interactive technologies or cognitive tool approaches are the focus of more research than ever before. Beaumie and Reeves (2007) built on Salomon's (1993) concepts of distributed cognition and argued: "… the learner, tool, and activity form a joint learning system, and the expertise in the world should be reflected not only in the tool but also in the learning activity within which learners make use of the tool" (pp. 207). Thus, as stated in the above quote, the learner or the user, the computing artifact and the activity or task are components of the learning system, forming a system of relationships as discussed in the earlier sections of this paper.

Considering the concepts of cognitive tools, and according to the theory of distributed cognition, the way cognition is distributed is first determined by the intentions of its designer. After that, it is determined by the tool's characteristics, for instance by tool affordances, forms and behaviors (Shackel, 1984). Hence, a cognitive or mind tool is essentially an artifact that should be designed in a way that accomplishes their purpose and communicates the designer's intentions (e.g., Crilly, 2010). In this regard, supporting reflective thinking is the purpose of the design and also the designer's intention. So, as with any other physical artifacts, it needs to be designed in order to function, thus it requires particular characteristics that enables that function—supporting cognitive activity and reflective thinking in its user (Ghajargar, De Marco, & Montagna, 2017).

Before going through the analysis and defining the ***make me think*** relationship, we will provide a brief section about related works, which have been undertaken in the HCI domain.

Related Works: *Designing for Reflective Thinking In HCI*

The interest in designing computing artifacts to support reflection, especially in the context of everyday lives, has been growing in the field of Human-Computer Interaction (HCI) since so-called *smart* devices have been able to collect data and communicate with the user.

In the HCI field, *reflection* refers to the action of thinking about the information provided by computing artifacts, in order to capture awareness about actions and experiences and also consequences (Baumer et al., 2014; Sas & Dix, 2009). The topic of reflection has been investigated from both a theoretical and a practical perspective in the HCI field. From a theoretical perspective, Fleck and Fitzpatrick, for instance, provided a framework summarizing the literature outside of the HCI field about reflection. They included in their framework three important aspects of reflection, namely purpose, condition and levels of reflection and then they listed technologies that could support reflection (Fleck, 2012; Fleck & Fitzpatrick, 2010). In a more specific way, Baumer et al. (2014) saw reflection as an alternative to traditional and persuasive ways of behavior change, especially for sustainable behaviors.

Mols, Hoven, and Eggen's (2016) *Technologies for Everyday Life Reflection* suggests a more holistic design space for reflection. Based on a literature study on tools and methods for reflection, they suggest three roles that systems can take in order to evoke reflection, dialogue-driven, data-driven and expression-driven reflection.

A focus on the materiality of interaction with physical smart objects and how it can influence human behaviors and evoke reflection has also been the subject of study in the HCI field and design (Ghajargar & Wiberg 2018; Wiberg, 2018).

From a digital artifacts perspective, Kalnikaite and Whittaker (2011) developed *MemoryLane*, a digital memory application that helps people to organize their digital mementos* according to the place, people and objects. *Echo* (Isaacs et al., 2013) is an android mobile application that helps users to reflect on their daily activities, with the purpose of increasing their well-being. *Echo* seeks to go beyond just being a tool to remember events with, by having a section for reflection on past events. It records events by not only including a brief description of the event, but also the degree of one's happiness and allows for the inclusion of photos and videos.

There have also been many experiments carried out from the physical artifacts' perspective. For instance, *Data Souvenirs*, by Aipperspach, Hooker, and Woodruff (2010), is inspired by environmental psychology and emphasizes the important role of the physicality and familiarity of objects that support reflection. *Lover's box*, by Thieme et al. (2011), is another example of such a physical, everyday artifact, and aims to evoke reflection on romantic relationships between couples.

Bowen and Petrelli (2011) used the concept of autobiographical memories and digital mementos as tools to help people reflect on their experiences in the home. In particular, *critical artifacts*, products of a critical design process, were used in a design study in order to enable users to envision ways of using technology in the context of personal experiences.

Considering reflection as a driver of behavioral change, a number of projects have investigated the role of physical artifacts in achieving such change. For instance, *Keymoment* (Laschke, Diefenbach, & Hassenzahl, 2015) is a key hook with the purpose of fostering more healthy and sustainable urban mobility behavior, by encouraging its users to take their bike key instead of their car key. In particular, the design of the key hook helps users to remember and reflect on the choice of transportation in a pleasant way, at the moment of leaving home. A similar idea of using a key hook as an artifact for reflection on urban mobility behavior has been conceptualized by Ghajargar, Giannantonio, and Ghajargar (2015), which has been inspired from environmental psychology and the theory of our implicit connection with nature (Schultz, Shriver, Tabanico, & Khazian, 2004). Mckinnon's (2016) *Domestic Reflections, Electric Reflections* focuses on the everyday mundanity and critical design as an approach for designing interactive and every-day objects for sustainable behavior change. The *Eco-Feedback Technology* is another concept, using digital and physical artifacts, mostly ambient displays to capture awareness about user behaviors (Froehlich, Fidlater, & Landay, 2010). Feng Gao's (2012) *Design for Reflection on Health Behavior Change* takes an instance on alternative ways to persuasion-based systems for behavior change specially in dietary context.

Reveal-it is another example of using large digital displays for empowering people, by evoking thoughts on energy consumption at both individual and collective levels (Valkanova, Jorda, Tomitsch, & Moere, 2013). Social interactions also seem to play a relevant role in the reflection process, because they require talking with other people about the experiences, helping to recall memories. For example, interactive systems for behavior change increasingly focus on multiple users, often to encourage open-ended reflection rather than prescribing a particular course of action (Ploderer, Reitberger, Oinas-Kukkonen, & Gemert-Pijnen, 2014). Reno and Poole's (2016) *It Matters If My Friends Stop Smoking* which also focus on the role of social support for behavior change.

What Tools for Reflection Are

Reflection as a cognitive process is influenced by either internal and individual, or external and collective, components. It is a way of problem solving in relation to an individual and internal activity, but is also about the relationships with artifacts, activities, places and people (Hutchins, 1995; Salomon, 1993). On the other hand, an artifact that can promote reflection can also become a medium for creating such relationships between a user and their daily activities. Therefore, it seems crucial to understand the relationships between a tool for reflection and other elements in the system (Hutchins, 1995; Salomon, 1993). Elements include the user, who uses and interacts with the artifact, and the artifact itself, which is the tool that makes the user think and reflect about an activity—that is, an activity required to achieve a functional goal. The tool can sense, collect and process data and provide feedback to the user. Other elements include the social environment, which determines and influences the way a user interacts with the tool and carries out the activity; the physical environment, which is the physical and spatial surroundings within which the user interacts with the computing artifact and carries out the activity; the activity that users undertake in order to accomplish a functional goal; and other artifacts—physical and digital—with which the tool is connected, physically or through Internet connectivity.

In an attempt to understand what a tool for reflection in everyday use might look like, drawing upon a vast body of knowledge in HCI about reflection, we developed a prototype of a lamp, which has some similarities, but also differences compared to ambient devices or eco-technologies. It is similar to an ambient device, because it is a lamp, it informs the user by providing visual light-based feedbacks. However, the design of our prototype differs from an ambient device, mainly in two ways: 1) this lamp is made of modular units and the user can touch and build it physically. This encourages the user to participate and be an active part of the light behavior, which reflects his/her behaviors. The lamp structure can also grow by adding extra units on top of it, which emphasizes even more on the design sensibility towards user's participation in building his/her own behavior; 2) changes in light behaviors that occur according to changes in user's habits, are designed in a way that show improvements and the quality. The light colors are natural white, and they do not change colors—e.g., red or green, the common light colors used in ambient devices—they just change the position from bottom of the lamp to the top and vice versa.

These characteristics and behaviors are also required in order to create the ***make me think*** relationship with the user (Ghajargar et. al., 2017). Throughout this experiment—building the prototype, and defining its characteristics and behaviors—we sought to understand and demonstrate the ***make me think*** relationship model.

The lamp prototype initially consists of three modular lighting units. It is able to receive data from a mobile application that collected data about user's urban mobility behaviors[2]—frequency and the choice of one means of transport over another. Then, units of the lamp lit from dim to bright, and from the bottom to the top of the lamp in order to show the improvements in user's sustainable urban mobility behaviors. The lamp interacts in different ways with other components of the system, namely: 1) with the user, who primarily interacts with the artifact for the purpose of understanding and reflecting on urban mobility behaviors, 2) with the social environment and the user, which is the relationship enabled between the artifact and its context, through its presence and appearance, and 3) with other artifacts and contexts, which were, for example, the mobile app and the two contexts of indoor, which is the home environment and outdoor, from which data were received.

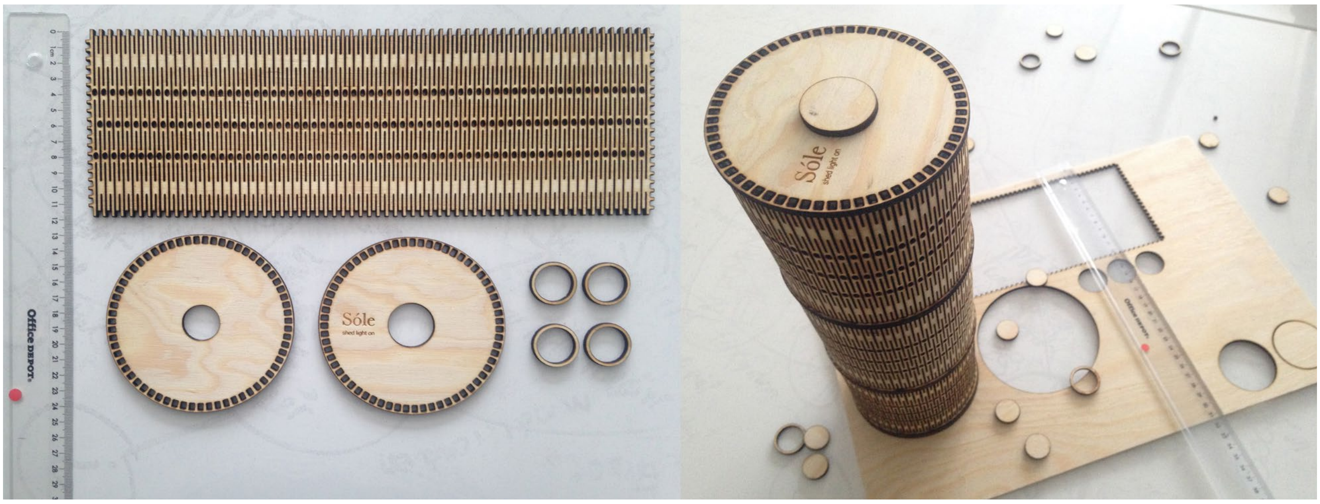

Figure 4. Prototyping the lamp.

First, we define the characteristics according to the three different kinds of interactions. Then we will analyze the lamp's behavior and structures in order to describe the model of the ***make me think*** relationship.

Interaction with The User: *The User's Engagement and The Tool's Transformation*

Physically being engaged and learning with tangible computing artifacts as active partners can enhance learning and cognitive development (e.g., Price, Rogers, Scaife, Stanton, & Neale, 2003; Rogers & Muller, 2006). In fact, arguably, this is one of the most important characteristics of a cognitive tool to be suggested since the development of the constructivism theory of learning and cognitive technologies (Jonassen, 1997; Piaget, 1947). A user interacts with an artifact, then the artifact provides feedback, creating loops of actions and feedback that can shape and personalize the interaction (Dietrich & Van Laerhoven, 2014, 2016). One opportunity to incorporate this property into the physical structure of the artifact is to build it out of physically modular units that also contain information, i.e., similar to Lego blocks. The modularity of the structure helps the user to be engaged more with the artifact and experiment with it, which is another important aspect of the learning process.

Accordingly, the lamp's physical structure has been designed to provide some of those possibilities for engagement. It consists of three unique modular units, so the user builds the lamp by physically manipulating and inserting the units. The structure also provides the opportunity to add more units to carry the light from bottom to top units (Figure 5).

As has been mentioned before, these properties are linked to the tangible and physical structure of the artifact. Therefore, they relate to behaviors, materials and shapes and so are visible to the user. Other important drivers of reflection, such as openness to interpretation, experimentation and exploration, are also supported by this level of interaction.

Interaction with The Environment and The User: *Communication*

Reflection is a process of making sense of one's experience, based on the meaning derived and communicated from past experiences (Dewey,1933). Building on a combination of two types of communication, namely that across time and space, this level of interaction turns the artifact's transformation and feedback into a *text* (Crilly et al., 2008; Shannon, 1948). Although the *text* remains open to interpretation in the context of use, it is still clear enough to convey the message. For instance,

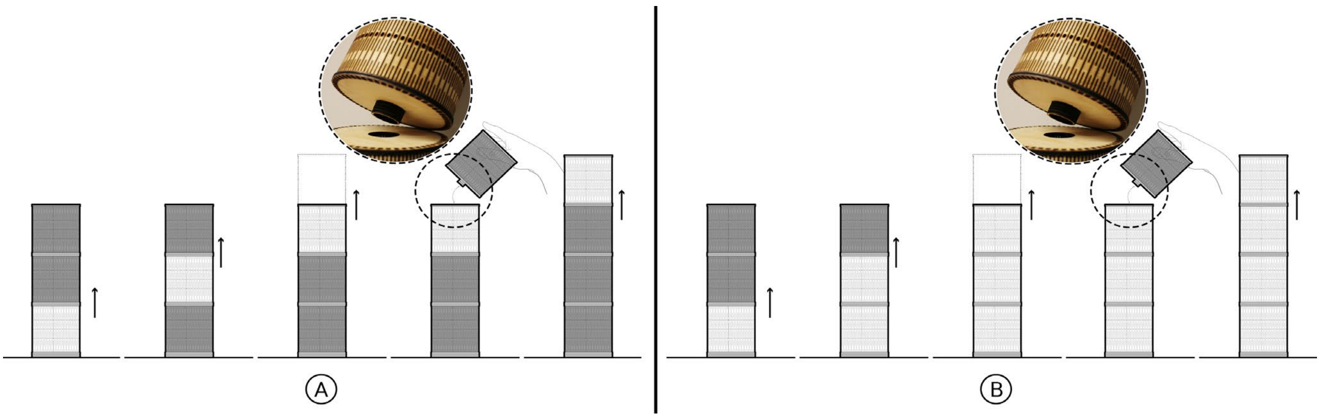

Figure 5. The lamp's modular units and its transformation.

the lamp carries information to the user—regarding their mobility behavior—by raising the position of the light alongside the structure.

Such feedback and its transformation is also defined as the carrier of information or the carrier of meaning in terms of embodied interaction (Dourish, 2004). The lighting behavior seeks to convey a simple message and meaning regarding the user's mobility behavior. In this prototype, we have designed two types of lighting behaviors: A) *to arise* mode and B) *to accumulate* mode (Figure 6). Both of these behaviors show to the user, whether she/he is progressing in sustainable urban mobility behavior. This message will be communicated through A) turn off light bulbs in lower units and turn on them in the upper units, which result in raising the position of light alongside of the lamp or B) turn on more light bulbs, which results in having increased number of light bulbs which are turned on (Figure 6). The user will have the possibility to choose a light behavior between these two options.

The lamp communicates this message with the user in an abstract, somehow qualitative way. It is also calm and requires little user's attention (Bakker, et al. 2015; Weiser & Brown, 1995). However, the numerical values are always accessible through the mobile application that collects data.

This is an alternative way of communication compared to the traditional ambient displays and eco-feedback technologies (changing in color from red to green), even though both share some principles. For example, eco-feedback uses also smart technologies to develop devices for the home environment to provide feedback on individual or group behaviors with the purpose of reducing environmental impact (e.g., Froehlich et al., 2010).

Interaction with Other Artifacts and Environment: *Deliberation*

This level of interaction happens between artifacts and artificial agents and their environment. The lamp is connected to other artifacts which can collect data concerning the means of transportation—for instance, the distance traveled in km, fuel consumption, the quantity of CO_2 emissions, etc.—and send it to the lamp. The mobile application is able to recognize the means of transportation—i.e., it is able to recognize if the user is taking the bus, cycling or walking—amongst other data that it collects.

At this level of interaction, which happens between artifacts (e.g., a car key, a bicycle, smartphone, a public transportation payment card, etc.) and the environment, the lamp performs a slow and careful kind of reasoning, helping to form an opinion and make a decision. This interaction between artifacts and the material environment enables the construction and modification of an agent's internal concepts, beliefs and goals. It is related to the internal structure of artifacts, thus is hidden from the user but is visible to other agents and artifacts (Fortino, Guerrini, & Russo, 2012; Gero & Kannengiesser, 2003; Ortin & Cueva, 2003).

As the intention for designing tools for reflection is to support people in their thinking and reflection, so the relationship that it forms with the user has some similarities to those of ***augment me***, ***engage me***, but is in contrast with ***comply with me***. The ***make me think*** relationship is an equal, balanced one, similar to the relationship between the user and the artifact in the ***augment me*** relationship—e.g., a calculator. In these relationships, the user collaborates with the artifact in order to carry out the task—i.e., reflection: thinking about an activity. The ***make me think*** relationship is similar to the ***engage me*** relationship, because the artifact engages and motivates the user, which is required for achieving a goal. The artifact is used also to encourage the user to think about, but not carry out, the task. So, the characteristics of ***make me think*** relationship show a mix of some features in ***augment me*** and ***engage me*** relationships. Whereas it is in contrast with ***comply with me***, because it is designed to change user's behavior, not to comply with them. Furthermore, ***make me think*** relationship differs from ***augment me*** since its purpose is not to augment user's abilities to carry out tasks, solving problems faster and in a more efficient way. It differs also from ***engage me*** relationship, since user might have not only a personal goal for using personal data, but also other goals that will be decided and defined later in time by user—e.g., reducing the negative impacts on environment by using more bicycle.

We believe this mixed characteristic of ***make me think*** relationship is a fundamental driver that might make tools for reflection part of a distinct category of interactive and smart artifacts (Figure 7). This certainly requires the building of a long-term, constant and enduring relationship between the user and the artifact. In order to build such a relationship, tools for reflection need to create thoughtful interactions with the user, instead of merely displaying information.

Figure 6. Two different types of light behaviors: A) to arise mode and B) to accumulate mode.

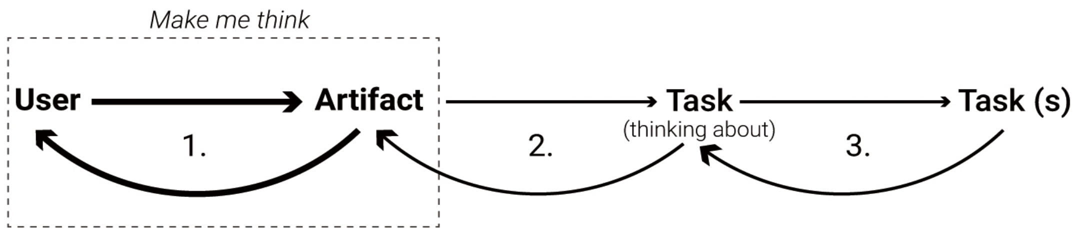

Figure 7. Make me think relationship model.

As an attempt to categorize a new kind of relationship with tools for reflection—which are computing artifacts that support reflection in their user—we can summarize the most important characteristics of the ***make me think*** relationship thus: 1) a balanced relationship and collaboration between the user and the artifact; 2) there is a very specific activity that has to be undertaken in relation to the artifact, that is reflective thinking—i.e., which should be related to another activity that needs reflection such as activities related to urban mobility behaviors; 3) the user always has overall control of this relationship; 4) the artifact in this relationship is used to encourage the user to think about, but not carry out, the task—e.g., driving, cycling.

The mobile app senses and collects data related to the user's mobility/transportation activities—walking, cycling, and driving—then the lamp lights up in particular ways according to the data received from the mobile app. The behavior of the lamp is the outcome of a system of relationships with other components that are connected to each other.

Discussion

Reflection as A Reference Task

Reflection as a way of thinking is not just an individual and internal process, but requires external stimuli: objects, other people, activities and the environment are all important in the process (Rogers, 1997; Salomon, 1993). Reflection needs continuity while helping people to acquire a deeper understanding of a situation and then take careful and informed courses of action for change (Dewey, 1933; Schön, 1983; Sengers, Boehner, David, & Kaye, 2005). Reflective reasoning is a deep, slow and effortful process (Norman, 1993). It requires moments of quiet, but also the aid of external support, such as writing, using computing tools, reading books, etc. Unlike experiential thinking, reflective thinking is not autonomous or reactive, but rather is about concepts, reconsideration, planning and decision-making. It is not about the elaboration of the information structure that already exists in our brain.

Reflection can be considered as a user activity or a reference task (Whittaker et al., 2000) that a computing artifact or a tool for reflection can support. However, a tool for reflection differs from other artifacts that support a user's activities, in some fundamental aspects: 1) the user does not necessarily undertake their daily activity using such artifacts—e.g., they do not drive or cycle using a lamp—rather the presence of the artifact supports reflection about other activities, the experiences and memories associated with it, so reflection can be considered as a process of thinking about an activity; 2) the user thinks about an activity *with* the tool for reflection rather than *through* it—i.e., it does not function as an object in the hand of its user, but rather as a partner. Accordingly, the reference task becomes a relational task that relates to the object (maybe over long periods) rather than serving merely as a tool for solving a particular task.

Reflection is, as such, not a task or a user's problem to be solved, but rather an ongoing activity that should be continuously supported. This is definitely a challenge for interaction designers—how to design tools for supporting a continuous activity (i.e., reflection), rather than designing for activities that can be essentially and efficiently solved as problems, which is the typical model behind the design of computational tools.

Implications for Design Theory and Research

In reflecting upon our own design process as it unfolded during this project, we have also identified a number of implications for the development of design theory, and implications for carrying out this type of research through design. First, a typical design project starts with a design problem or a design brief. However, reflection is not a problem to be solved, and we already think with objects (Turkle, 2011). So, instead of tackling the project from one such perspective, we needed to design our project as a process that would encompass reflection as an activity being empowered with computational tools. At the same time, we know that any tool changes the activity it supports, no matter whether the tool is a hammer or a smart object. Accordingly, we not only had to maintain a focus on reflection as an activity undertaken with this object, but also had to keep revising our ideas about what reflection is on a more theoretical level, as we moved forward in this project. The more general lesson to be learnt from this is that it is not only design that redefines tasks, or resolves problems (on a practical level), but also design projects that challenge and change the ideas guiding the design. Therefore, design concepts should not be seen as a starting point for a design project, nor be seen as a stable construct throughout a project, but rather as a theoretical factor that also changes as the project moves from early drafts to the final design. Design theory (and to theorize design) is not separable from the design process, just as our everyday objects that we think with cannot be separated from the activity of reflection.

If our theoretical notions change over the course of a design project, then that also has implications for the research design. This project, with a focus on designing for reflection, has identified this fact, and has illustrated how the design research not only needs to be iterative in terms of alternating between theories on reflection and practical design work in designing for reflection, but how each step of the research process needs to bridge between the design concepts that guide the design process, and the designed artifacts that illustrate the ideas in material and computational form.

Implication for Designing IoT Systems

There are a number of additional lessons to be learnt from this project, not only in terms of designing for reflection, or how this project in itself has been a reflective process where we have alternated between ideas about reflection and how those ideas can be manifested and expressed in the design. There are also lessons to be learnt and implications to be derived for the design of IoT systems in general. First, the design of IoT systems is about the design of a system of objects where 1) the connectivity between the objects is a central assumption, and 2) where *objects* are clearly distinguishable from each other. As a consequence, any design approach to the IoT is simultaneously about bringing pieces (or objects) together, and about keeping things (objects) apart. While this is a general concern for any IoT project, it becomes very clear when designing IoT systems for reflection. As *thinking with objects* is such an inseparable activity, it becomes hard to separate the *object to think with* from the person who has a reflective relationship with the object. On the other hand, the notion of *smart objects* has brought with it a conceptualization of computational power in material form. A smart object is typically something computational, but also physical. Accordingly, and from that perspective, *smart objects to think with* manifest this general design challenge of simultaneously designing standalone entities while also designing these entities to work in concert—as a system.

Conclusion

In this paper, we described four models of IoT systems which have four different simple relationships with a few essential components, but all of which can be scaled up to include more users, artifacts and environments (Brown et al., 2017). From a systems perspective, this modeling technique: 1) highlights that the environment created by objects is about the relationship between artifacts; 2) shows the evolution of technical systems that enable building such IoT systems, and 3) gives a systemic understanding of the object and its user, and how such relationships enable people to undertake new tasks, think differently and solve complex problems. There are emergent aspects of the system, such as the relationship that the user makes with the artifact. From this perspective, it is the emergent aspect, not the artifact itself, that is of central concern.

We are moving towards the development of smarter computing artifacts, artificial intelligence for the so-called Internet of Things (IoT). The IoT has been defined as a network of computing artifacts, people and environments, which are connected and communicate with each other through Internet connectivity. They can sense, collect and exchange data, and provide feedback. Our environments are increasingly filled with such networks—e.g., Google home, *nest* thermostat, *Alexa* devices, etc.—and we constantly interact with them in our daily lives. These systems of things are, to a large extent, about relationships between people, objects, places, and activities. Therefore, it seems reasonable that, being surrounded by such networks, we should try to understand our relationships with them. In order to understand our relationships with such systems, we proposed simple models with few components. We suggested also a relational approach in order to help us to understand and design such IoT artifacts and systems that support different types of user activities. This relational approach can not only offer a better understanding of the existing IoT artifacts/systems and their internal relationships between the user, user activity and the situation, but can also support the design of new IoT artifacts/systems. This is particularly relevant for designing computing artifacts in a system that aims to support reflection where reflection is seen as an activity which is relational in nature, as described by the distributed cognition theory.

This modeling approach helped with an analysis of three examples of existing relationships with computing artifacts, namely: ***augment me***, ***comply with me,*** and ***engage me***. We sought to explain the characteristics and the components of these relationships using examples. Then, as another example, we focused on the ways computing artifacts can support reflection of a user. After providing a brief study of literature on reflection, related works in HCI and cognitive technologies, we presented some properties of such artifacts using a prototype lamp. Building upon its characteristics, which were engaging, transformative, communicative, and deliberative, we created the model of the ***make me think*** relationship.

In addition, in this paper, we have identified the fundamental components of an IoT system as being: 1) the user; 2) computing artifact; 3) user's activity or task, and 4) situation—which is the context within which the activity occurs and also other computing artifacts connected to the system. Then we discussed 1) reflective thinking as an activity, which is of increasing interest and importance to the HCI and design communities, 2) our methodology and how it can contribute to on-going design research methodologies, 3) the implications for designing IoT system.

We believe the analysis of the relationships in an IoT system becomes even more relevant as we increasingly consider the design of ecologies and systems of smart artifacts, and consider reflection as a concept in design outcomes, especially in the design of smart and interactive artifacts (Ghajargar & Wiberg, in press).

We conclude our paper by providing some suggestions for future research: 1) designing artifacts for the Internet of Things is actually about designing a system which is, to a large extent, about the relationships between its components, and how we define and understand these relationships is crucial for designing future IoT systems; 2) the user activity in this system can define the relationships between the user, computing artifact and situation; 3) in systems designed to support reflective thinking, the sensory and physical characteristics of the artifact itself play crucial roles—e.g., its behaviors and affordances, and 4) reflective thinking can be considered as a reference task in HCI itself, but is distinguished from other tasks because it is related to another user activity.

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Endnotes

1. As the operations of installing and adjusting are often necessary in order to run and use any kind of computing artifacts, so have not been considered in models as components.
2. This is part of a project in collaboration with Telecom Italia Mobile Open Innovation Center.

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