Towards the Design of Intelligible Object-based Applications for the Web of Things.

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ABSTRACT
As more and more things, sensors, appliances and devices are getting connected to the Internet, researchers of the Web of Things community have recently been exploring the use of the World Wide Web as a platform for smart objects. Such technology enables the creation of object-based applications mixing real-world objects that embed tiny Web servers with existing Web resources. To ensure the adoption of such applications, which potentially modify the behaviors of objects, it is needed that the overall system or architecture supports the mental models developed by users. In this paper, we propose a definition of object-based applications based on the literature review and present a protocol aiming at better understanding users' perception of smart environments. We then present our preliminary results and highlight the need of creating intelligible systems and tools.

Categories and Subject Descriptors
H.5.m [**Information interfaces and presentation (e.g., HCI)**]: Miscellaneous.

General Terms
Design, Experimentation, Human Factors.

Keywords
Web of Things, Object-based Applications, Physical Mashups, Mental Models, User Perception, User Study, Intelligibility, Smart Objects, Smart Environments.

1. INTRODUCTION
The Web-enablement of physical artifacts (e.g. tagged or visually marked things, networked sensors, appliances and devices embedding web servers) today opens up the possibility for small applications to be built on top of real-world objects (RWO). By exposing these smart objects as accessible and addressable resources of the World Wide Web, researchers of the Web of Things community demonstrated that popular Web technologies (e.g. HTML, Javascript, Ajax, PHP) could be used to create applications mixing RWO and existing services of the Web [3,4,7,17]. Following the trends of Web Mashups (i.e. ad-hoc applications) and participatory services [9], they promise to provide developers and proficient users with new tools to compose resources not only from the digital but also the physical world. Such technologies would allow end-users to customize their RWO, to augment their capabilities and to shape new behaviors that will lead to the creation of smart environments.

So far, projects and initiatives have mainly focused on building system architectures, defining semantic descriptions of RWO capabilities or status and offering human-understandable representations. If several mobile browsers providing users with a new means of visualizing digital counterparts of RWO and to interact with them have recently been presented [3,5,16], the concept of object-based applications has just started to be explored and is not yet clearly defined. Researchers often assume that users will most likely want to create or pull applications on top of their RWO and arbitrarily recombine them according to their needs [10]. We argue that such a vision can only be achieved if the overall system matches users' mental models. The way object-based applications are functioning and their impact on RWO's behaviors need to be intelligible for people if we want them to use, manage and interact with smart environments.

In users' mind is there such concept as object-based applications? How do non-technical users perceive interconnections between RWO and Web resources? How consistently do they consider these applications as being part of a RWO or the environment? Although researchers and designers may represent applications in a principled, logical fashion, user perception of "disappearing systems" is rarely systematic [15]. By blending in a seamless way into user's environment, charging RWO with additional functionalities and making them act in a proactive way, these applications are indeed modifying our perception of inner systems. It is therefore time to consider the type of representations people make without regard for technical concerns.

To ensure the user adoption of the Web of Things approach, we propose to investigate people's perception of interconnected RWO and Web resources. To do so, we asked a group of users to draw a schematic representation of a smart environment (i.e. an ecosystem of smart objects interconnected with Web Resources) and conducted a collaborative evaluation of their productions. After reviewing the related work and trying to define object-based applications, we present in this paper the protocol and the first results of our qualitative research. We argue that this work contributes to Web of Things research by better defining object-based applications and providing insights into users' mental models. Our results will help researchers to build systems that support these models and designers to create intelligible user interfaces.

2. DEFINING OBJECT-BASED APPLICATIONS

Inspired by Kindberg's work on "web presence" [8], the Web of Things community managed to expose RWO as resources of the Web and created a new type of application built on top of the real world. In this section, we review the related work on object-based applications and then highlight their capabilities. We finally identify three types of applications that could be presented in different ways to users.

2.1 Related work

Wilde first pointed out the advantage of fully integrating "things" into the Web with a RESTful approach [17]. He tells us that Web-exposed objects can be reused in different contexts or applications as any accessible Web resources and facilitate the creation of applications linked with the physical world (e.g. a backend infrastructure to monitor and manage products of shop or warehouse). Guinard and Trifa later refer to these applications as "physical mashups" [6] that can be categorized in two groups: "physical-virtual mashups" presenting a user interface (e.g. a dashboard monitoring the energy consumption of household appliances) and "physical-physical mashups" enabling machine-to-machine interactions (e.g. a lamp that changes its color depending on the energy consumption level).

In recent work, Guinard presented two "mashup editors" [5] offering people to program their RWO according to specific rules or events (e.g. augmenting the home temperature when a user is coming back home). Benoit et al. describe such applications composing RWO or Web resources that are "functionally not compatible" as "complex" [2]. As opposed to chains of objects based on objects' input / output capabilities, "complex applications" embed the computational logic that is required to bridge any RWO with another (e.g. as illustrated on Figure 1). In a similar approach, Thébault et al. finally use the generic term "object-based applications" [16] to refer to any application interconnecting a RWO with other objects or Web resources that have been designed to support a specific task in an environment.

2.2 Capabilities of applications

Based on the related work, we propose to highlight the potential capabilities of such applications. Developers and proficient users can use Web of Things technologies to leverage the mechanisms described in the following paragraphs.

Capacity to deliver Web content or media through RWO whose output capabilities are compatible. Data stream can whether be queried from Web resources (e.g. using the LCD screen of an alarm clock to display Tweets) or others RWO (e.g. redirecting a video stream from a laptop computer to a video projector). Information can potentially be converted or reformatted by the application to be conveyed through the chosen RWO (e.g. a text can be read if no display is available).

Capacity to publish information related to RWO's states on Web Resources. Data related to RWO's daily uses or capabilities can be logged for personal use (e.g. generating graph from a user's TV watching time) or processed to be shared on other Web resources (e.g. posting on LastFM all songs that are being played on my hi-fi system). Publishing rules can eventually be implemented in order to avoid user-sensitive information to be broadcasted on social network platforms (e.g. posting a message on Facebook only when I lose weight).

Figure 1. A mobile "object browser" allowing users to download object-based applications on their RWO.

Capacity to trigger RWO's capabilities based on RWO's states. RWO can be turned on/off or fine-grained controlled by applications in order to automate the home (e.g. setting up the heaters and shutters according to temperature and light sensors) or stress events of the physical world (e.g. making a lamp blink with a different color when a user receive a phone call). Commands can also be chained and be sent after a specific user's interaction with a RWO (e.g. automatically reducing the light intensity and declining calls when a user is turning his DVD player on).

Capacity to modify the behavior of RWO based on Web resources. Multiple data streams can be queried and processed from Web Resources in order to augment the awareness of RWO and leverage an ambient intelligence. The inner working of objects can be bypassed to anticipate unexpected events (e.g. a digital video recorder can be reprogrammed if a TV show has been rescheduled to another time slot) or warn the users of important matters (e.g. displaying a customized alert on a TV when a family member is sending a real-time message to a user).

2.3 Types of applications

By combining the mechanisms described in the previous part, developers and proficient users are able to create more or less complex object-based applications. Another way to highlight the variety of these applications is to consider them according to their impact on the physical world. We argue that they can whether enable users to monitor, augment or orchestrate their RWO. We propose three categories that are described hereafter.

Applications that monitor RWO. Most likely designed for computer or mobile displays, these applications provide users with a comprehensible overview of a small or large scale RWO's ecosystem. They facilitate the aggregation, the storage and the presentation of RWO's states and may offer remote control of their capabilities.

Examples: social networks for "things", smart metering tools related to energy consumption or daily life activities (i.e. life logging), inventory and tracking systems facilitating asset management, etc.

Applications that augment RWO. Specifically designed for a type or model of RWO, such applications offer users to add one or several capabilities to an object. They enhance the inner system of RWO by enabling a new means of interoperability with RWO and Web resources and allow users to customize their product's experience.

Examples: facilitating data circulation among devices and Web resources, adding a social dimension to RWO, enhancing RWO's awareness with open data, suggesting short interactions with Web services (e.g. postponing a meeting or sending a "templated" email from a RWO), etc.

Applications that orchestrate RWO. Involving multiple interconnections of RWO, this type of application aims at augmenting the environment. They allow multiple RWO of a physical space to be automated according to a given context. Spatiotemporal and social information, often provided by Web resources, allow users to define events that will trigger or adapt the behaviors of RWO.

Examples: automation of household appliances and activities (i.e. domotics), assisted living systems for elderly people, RWO reconfigurations for ambience sharing or communication purposes, personalization of content delivery according to social preferences and presence, etc.

3. INVESTIGATING USER'S MENTAL MODELS OF OBJECT-BASED APPLICATIONS

By mixing RWO and Web resources, object-based applications open up the possibility for physical artifacts or environments to be augmented and orchestrated. These applications, which modify the behaviors of RWO, raise new issues regarding users' understanding of complex inner systems. As researchers are working towards the design of new tools allowing people to create, deploy and manage object-based applications, it is needed that their architecture supports users' mental models. In this section, we present the protocol and the preliminary results of an experiment that aims at capturing the mental models of a smart environment.

3.1 Overview

Rouse et al. [13] proposed a comprehensive definition of mental models, which has also been quoted by Schmitt et al. in their research on "disappearing systems" [15]: "Mental models are mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states". In our research, we especially seek at better understanding users' structural mental representations of object-based applications, described by Preece [12] as the internal working of a system. We are indeed interested in better knowing how users perceive the interconnections between RWO and Web resources and envision such applications.

As smart objects and object-based applications have not yet been introduced in users' life (i.e. except from Nabaztags, smart meters, televisions or radios have not hit the French market yet), we propose to build a protocol that will allow participants to

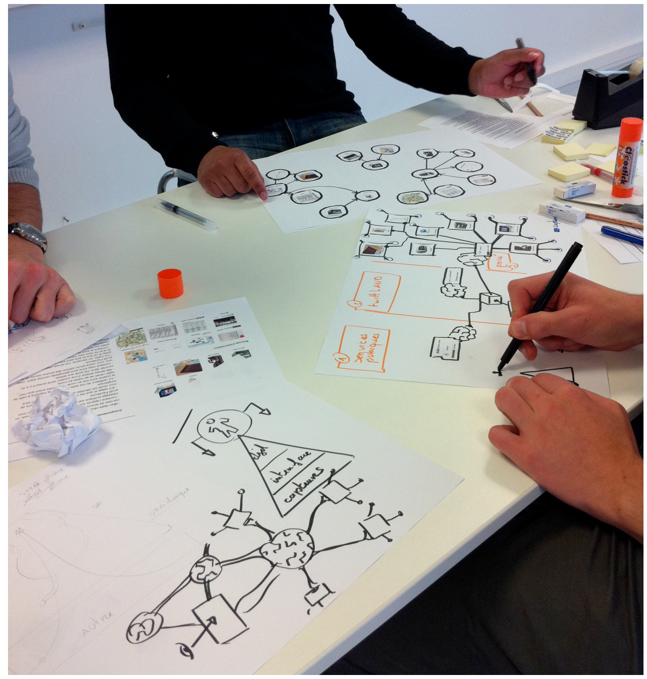

Figure 2. Participants sketching a smart environment

project themselves in a simulated reality involving well-known RWO or Web resources. By asking them to draw a schematic representation of a non-existing but functioning smart environment (i.e. depicted in a provided use case scenario), we expect to extract their mental models. Since people generally do not develop the same mental model of a system [11], we will focus on measuring users' understanding of the different representations or schemas. This will allow us to identify the different strategies used by users.

In order to enable successful interactions with computer systems, Sasse [14] tells us that designers and engineers need to create and communicate a user model that can be adapted by people. It is therefore necessary to collect users' mental models in an early design phase.

3.2 Participants

The sample of participants included six students between the ages of 23 to 27 years (M=23.6, SD=1.7). All of them were undergoing a full time post-graduate master's degree in a French design school where they have just started to work on smart objects, mainly from a product design perspective. All the students accepted to freely participate in our research program, which has been conducted with the agreement of the school representatives. During the same day, participants took part in a co-creation session aiming at combining RWO and Web resources to create new applications. They were therefore introduced to the overall concept of object-based applications but were not aware of research initiatives conducted in the academic field. We argue that their limited background on smart objects and their interest in the topic should not be considered as a bias but as a prerequisite to apprehend such a concept. Pre-tests of this experiment showed that "regular" users are most likely not able to project themselves in a world where objects and Web resources are combined to create applications.

3.3 Materials

Each participant was provided with a printed use case scenario describing a smart environment. Eight well known RWO and eight existing Web resources were arbitrarily chosen to build object-based applications that aim at supporting users' daily life activities. These applications vary in their level of complexity and rely on different types of interactions. In order to investigate users' perception on object-based applications, we only described their behaviors in the use case scenario. Instructions were reported as followed:

- Every morning, my alarm clock plays a song from my Deezer playlist (i.e. a music on demand platform) to wake me up.
- When I press the snooze button, a public message is automatically published on my Facebook profile.
- The alarm time will be automatically delayed if snowfalls have caused serious traffic jams.
- The bathroom heater and the coffee machine will be automatically turned on before the alarm of my alarm clock is fired.
- My multi-color lamp will turn green if I received some letter in my mailbox.
- My digital photo frame will display Facebook pictures of my friends when they are at my place (i.e. their position is retrieved from Google Latitude).
- Every morning, during weekdays, my lamp blinks with a red color to warn me that I have to leave now if I do not want to miss the metro. The schedule is fetched from RATP's website (i.e. Paris public transport).
- Shutters and lights of my place will be automatically triggered to simulate a presence when I am on holydays somewhere else (i.e. the dates are retrieved from Google Calendar).

A questionnaire based on a six-point Likert scale (i.e. from 1 corresponding to totally agree to 6 which indicates that they totally disagree) was given to participants. They had to answer these four questions:

- The schema is clearly understandable.
- I clearly see the links between RWO and Web resources.
- I understand how to activate or deactivate an object-based application.
- The schema will help me to manage my applications.

Paper (i.e. A3/ledger size), glue, scissors, colored pens and cards representing the RWO and Web resources mentioned in the scenario were finally made available to users during the session.

3.4 Procedure

This experiment was divided into two parts. The first one focuses on sketching the given smart environment and the second one on evaluating the schemas produced by all participants.

During the first phase, participants had 45 minutes to draw the interconnections of RWO and Web resources that were described in the provided use case scenario. To make sure that they come up with a personal representation of the smart environment, they were asked to work on their own. They were notified that there are neither good nor bad representations and that they could either draw items or use the printed materials.

During the second phase, schemas were self-evaluated by all the participants. Each representation was anonymously displayed on a white board and examined by users with a questionnaire.

Table 1. Status for mean evaluations of schemas

Schema	Schema clarity	Links clarity	Activation/ Deactivation	Helpfulness for application management
1	3,3	2,2	3,5	2,5
2	3,3	2,7	4,2	3,5
3	3,5	2,2	3,7	3,8
4	2	1,8	4,2	2,5
5	2,2	1,8	3,7	2,8
6	2,3	2,7	4,5	3

3.5 Results

As questionnaire criteria were evaluated in a different way, we discriminated positive evaluations from negative evaluations. We considered all ratings lower than 3.5 of the Likert scale to be positively perceived and ratings higher than 3.5 to be negatively perceived. To facilitate comparison and analysis, all positive evaluations have been highlighted. In table 1, we present the results that allowed us to identify the schemas that have been best perceived globally or according to a specific dimension. All schemas are shown on figure 3 and available for download [1]. Observations are detailed as followed.

Clarity of schemas. We observe that, apart from schema 3, all representations of the ecosystem are considered as clearly understandable. Schema 4 has the best score regarding the perception of clarity.

Clarity of links. Interconnections between RWO and Web resources are well understood in all visual representations. In schema 4 and 5, links are nevertheless considered as the clearest.

Understanding how to activate or deactivate an application. According to the participants' point of view, none of the representation clearly indicates how to control object-based applications.

Helpfulness for application management. Schemas 1, 4, 5 and 6 received positive evaluations, but schemas 1 and 4 are considered as more relevant to manage a collection of applications.

Global evaluation. Participants globally best perceive schemas 4 and 5. Even though they received the same average evaluation for the link clarity, schema 4 is considered as more intelligible and helpful for application management.

Users' feedback tells us that the third criterion was not well understood by participants. If most of them were able to apprehend the interconnections of objects with Web resources, the concept of user-managed applications that can be turned on and off seems not to be envisioned. This can be explained by the fact that users did not explicitly represent object-based applications in their drawings, as discussed in the following section.

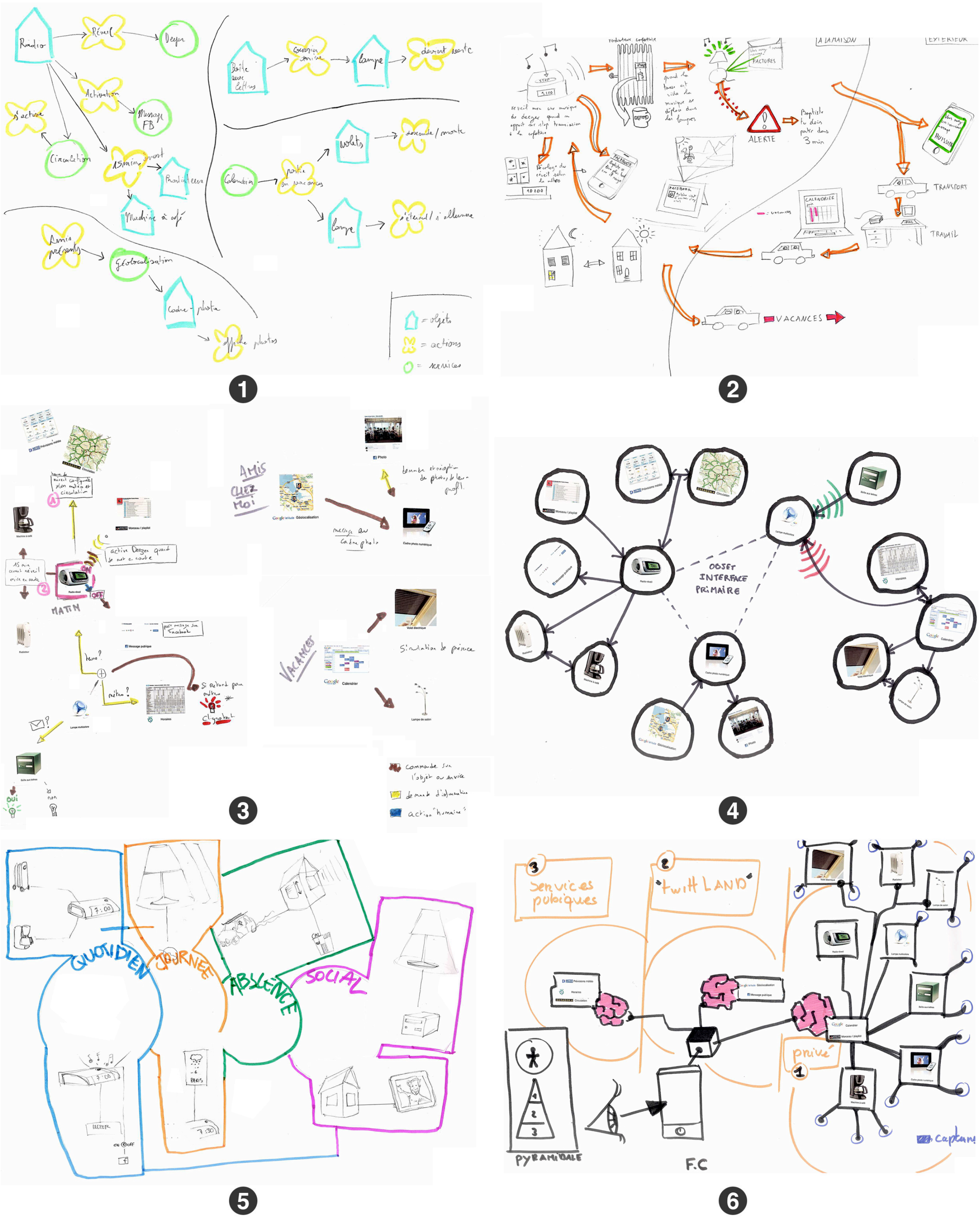

Figure 3. Schematic representations of a smart environment involving RWO and Web resources.

4. DISCUSSION

Out of the six participants, four came up with an abstract representation where RWO or Web resources are connected by links. In most cases, RWO and Web resources can be considered as nodes of small graphs whose orientation depend on the number of interconnections they have with each other's. By observing the way such graphs or clusters are directed, we found out that participants make a difference between interactive systems that rely on a specific RWO to operate and the ones that are based on information provided by Web resources. In schemas 1, 3 and 4, users for example considered Google Calendar, Latitude and the subway platform as the starting of point of a chain of interactions whereas the alarm clock and the lamp seems to articulate others RWO and Web resources. It confirms that people are likely to "attach" behaviors on RWO when interconnections aim at augmenting RWO's capabilities and reinforcing their role in the ecosystem. As the orchestration of RWO often relates to a particular situation or context, other behaviors have less opportunities of being embodied in physical artifacts and might be considered as "floating" in the environment. Especially in schema 5, a house was drawn to convey that idea.

Although participants did not mention the term "application" during the exercise, we can nevertheless assume that such concept is inherent in their representations. Schema 3 is for instance organized with three labeled clusters that support users' daily life activities (i.e. prepare to go to work, receive friends, go on holidays). If applications that orchestrate RWO appear to be easier to apprehend, those that augment RWO remain fuzzy. Participants are indeed likely to arbitrarily decide how interactions with RWO and Web resources can be grouped or split. For some participants (i.e. schemas 1, 3 and 4), each interconnection adding capability to a RWO can be interpreted as a subpart of a unique application (e.g. the one dedicated to the alarm clock). For another one (i.e. schema 5), each of them can be considered as ad-hoc applications that can be "pulled" on RWO like mobile applications can be downloaded on smart phones. This leads to small variations about the way applications are "anchored" on RWO (e.g. which RWO, from the mailbox and the lamp, should depend on the other?).

Even if object-based applications are not clearly perceived by participants, it is encouraging to see that most of them were not reluctant to merge the physical and digital worlds in their representations. Schema 6 tells us that separating the private, semi-private and public spheres is not a proper strategy to represent the interactions between RWO and Web resources. Splitting objects and Web resources into different categories make the links between each of them very hard to retrace. Instead of linking resources all together to create a global ecosystem (e.g. schema 4), some participants emphasized the separation between clusters or grouped them in a way that relates to their personal life (i.e. the different phases of a day). In schema 5, user draws meta-clusters (e.g. every morning, week day, absence, social) of what can be interpreted as object-based applications. In this case, the same RWO appear several times in different categories. It is worth mentioning that this representation is considered by participants as one of the easiest to understand, despite the fact that it does not provide users with any detail on the type of interactions (i.e. descriptions, flow charts and link directions were not used). We argue that such temporality-based or activity-based categorization may not only help users to have a global understanding of a smart environment but also to manage and navigate through their collection of applications.

5. CONCLUSION

In this paper, we presented an overview of initiatives leveraging Web of Things technologies to create new types of applications bridging the physical and digital worlds. To better define these object-based applications, we highlighted their capabilities in terms of interactions with RWO and Web resources and presented them in three categories: applications that monitor, augment and orchestrate RWO. While the first type is most likely to be accessed on a computer or a mobile for management purpose, the two others enables developers and proficient users to modify the behavior of existing RWO, whose user interfaces have not yet been designed for capability reconfiguration or augmentation. Such applications have therefore an impact on users' perception of inner systems that may influence users' adoption. Whether researchers work towards creating programming tools or designing browsers for application instantiation, it is needed that their systems support the mental models users are likely to develop.

In order to investigate users' understanding of a smart environment that could be created using Web of Things technologies, we conducted an experiment whose protocol is based on users' drawings of a given set of resources and self-evaluations of produced representations. We argued that this procedure would help users to project themselves in a simulated reality and help us to understand their perception of RWO and Web resources interconnections and interactions. In a first step of our research, we intended to capture mental models and observe if the concept of object-based applications is underlying them. We found out that applications can whether be "attached" to a RWO or be "floating" in the environment. In the first case, applications add capabilities or rely on a system event to trigger other RWO. In the second case, interactions are triggered among several RWO according to a spatiotemporal context often brought by a Web resource. Although participants did not explicitly mentioned the term "application", the way they represented interconnections and grouped RWO tells us that such concept make sense for them.

In future work, we plan to re-conduct our experiment with different panels to validate our findings. We also plan to add a qualitative evaluation to our experiment in order to better analyze users' production and investigate their understanding of the object-based application concept. We expect to collect insights that will help us to better understand how people are likely to consider and use such applications. We argue that researchers need to considerate users' mental models to create user-driven systems or architectures that will support these models. Designers also need to leverage this knowledge to create intelligible navigation or management tools that will help users to understand how their smart environment is orchestrated. We expect to contribute to the Web of Things community by providing guidelines for object-based application creation, instantiation and configuration by end-users.

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