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From Smart Objects to Smart Experiences: an End-User Development Approach

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Abstract

The growing availability of smart objects is stimulating researchers to investigate the Internet of Things (IoT) phenomenon from different perspectives. The potential of this technology is evident in different domains. In Cultural Heritage (CH), it may enhance access to CH collections, in order to ensure a more engaging visit experience and to increase the appropriation of CH content by visitors. So far, research on IoT has primarily focused on technical features of smart objects (e.g., how to program sensors and actuators), while there are very few approaches trying to facilitate the adoption of such a technology by end users. This lack limits the social and practical benefits of IoT; it creates barriers in all those usage scenarios where people would like to define the behavior of smart objects but they might not have the required programming skills. This is becoming evident in CH sites, where different stakeholders would benefit from managing ecosystems of interoperable smart objects to create enhanced visit experiences. This article presents a visual composition paradigm that allows non-programmers to synchronize the behavior of smart objects, thus determining more engaging user experiences. It discusses how the paradigm suites the need of curators and guides of CH sites to define *smart visit experiences* through which visitors can acquire CH content by interacting with the surrounding environment and the smart objects included in it. A serious game designed with professional guides of CH sites is used as a case study to show the potential of the presented approach.

Keywords: Internet of Things; Smart Object Modelling; Smart Visit Experience; Cultural Heritage

1. Introduction

People are becoming increasingly aware that Cultural Heritage (CH) must be value-enhanced: it is a legacy from the past that should be passed on to current and future generations, to help people construct their cultural identities [Copeland 2004; Merriman 2004]. Novel information and communication technology can support a greater awareness and appreciation of CH content by different people. There have been several initiatives in the last years to increase visitor engagement through different types of technology [Ardito et al. 2015a; Ardito et al. 2012b; Hinrichs et al. 2008; Not et al. 2017; Stock and Zancanaro 2007]). Recently, the Internet of Things (IoT) has emerged as a very promising technology able to enhance the access to CH collections. IoT systems are based on distributed software services that, through the Internet, enable the access to functionality and data provided by physical devices. These are the so-called *smart objects* [Atzori et al. 2010], i.e., devices generally equipped with sensors (able to detect different types of events occurring in an observed environment) and/or actuators (able to enact some actions determining a state change in the environment or in the IoT system itself). Through this technology, it is possible to create objects that visitors of CH sites can bring with themselves, touch and manipulate for experiencing the site by receiving personalized information [Petrelli and Lechner 2014; Risseeuw et al. 2016; Zancanaro et al. 2015]. The interaction with such tangible objects favors emotions and engagement, improves understanding, thus increases the appropriation of CH content [Petrelli and Lechner 2014]. Some works in the literature indeed recognize the benefits of physical manipulation and action as an additional channel for conveying information, since they activate real-world knowledge and improve memory [Manches 2011; Yannier et al. 2016].

Despite the advantages that this new technology offers, there are still important issues to be solved to increase its practical impact. The growing availability of smart objects has stimulated researchers to investigate the IoT phenomenon from different perspectives. However, even in the CH domain, research has primarily focused on technical features, e.g., how to program networks of sensors and actuators and how to ensure their interoperability [Chianese and Piccialli 2014; Mighali et al. 2015; Piccialli and Chianese 2017a; Piccialli and Chianese 2017b]. Very few approaches try to facilitate the configuration of smart objects, but their advantage is limited to programming single objects that the visitors bring across the CH site to receive personalized content when they reach hot spots [Petrelli and Lechner 2014]. It is still hard for CH experts (e.g., site curators and professional guides) to synchronize the behavior of multiple devices in order to create visit experiences where different sensors and actuators, installed in the environment or embedded in tangible objects manipulated by visitors, actively react to some detected events.

To fill this gap, this article presents an End-User Development (EUD) approach that, by means of a visual composition paradigm, allows non-programmers (simply called *end users*) to synchronize the behavior of multiple smart devices. As largely recognized in the literature [Ardito et al. 2012a; Costabile et al. 2007; Fischer et al. 2004; Lieberman et al. 2006b], EUD methodologies fit very well the requirement of letting end users customize systems for their situational needs.

Our visual composition paradigm supports CH sites experts in defining *smart visit experiences*, which allow visitors to interact with the surrounding environment by means of smart devices installed in it, to acquire the CH content and pursue some learning goals. With respect to other approaches, our composition metaphor promotes smart objects as entities characterized not only by native events and actions (as conceived in many IoT platforms) but also by *attributes* that the domain experts (i.e., the designers of the smart experience) can define to assign semantics to the objects. The aim is to favor the creation of digital narratives threads that professionals themselves can put in context with respect to the CH site content. The EUD paradigm then offers the possibility to adapt easily such narratives to different visitors and different types of smart experiences. It is based on a lightweight process intermixing design and execution activities. The adoption of visual constructs allows domain experts to design easily - and modify, if needed - the rules governing a visit experience, and simply execute it without warring about technical details.

This article discusses the abstractions at the basis of the proposed composition paradigm and shows that they were instrumental to customize an EUD platform previously developed, i.e., EFESTO-5W [Desolda et al. 2017a], to the configuration of smart visit experiences in CH sites. The customization activity is based on the outcomes of studies performed to analyze, in real conditions, the potentials and limitations of our approach. The studies involved fourteen professional guides of different CH sites in Southern Italy. The results provided indications on the practical value of the platform in this domain, as well as useful insights for further refining the composition paradigm.

The article is organized as follows. Section 2 discusses some background concepts, also related to our previous research in the CH domain; it reviews some prominent approaches that, in line with our research, aim to facilitate the adoption of smart devices within CH sites and illustrates the motivations that led us to extend our previous platform for EUD of IoT systems [Desolda et al. 2017a], in order to allow end users to augment smart devices with semantic attributes. Section 3 reports on the elicitation study that allowed us to observe, discuss and get hints on how curators and guides of CH sites would create smart visit experiences. Thanks to this study, we identified some conceptual elements that can favor the process of assigning semantics to smart devices and elaborated three scenarios that are described in detail. Section 4 describes such abstractions as the main ingredients of the proposed composition paradigm for smart visit experiences. Section 5 illustrates the new platform prototype that implements the visual composition paradigm, called EFESTO-SE (EFESTO for Smart Experiences). Section 6 reports on an evaluation study conducted with fourteen professional guides to validate the implemented composition paradigm with respect to the mental model of the end users. It also discusses some design implications. Finally, Section 7 concludes the article and outlines our future work.

2. Rationale and Background

Cultural heritage (CH) is increasingly supported by technologies that foster a better fruition, appreciation and understanding of museum exhibitions, archaeological parks, monuments. Currently, in most CH sites professional guides use mobile apps and interactive displays to enhance the presentation of the content exhibited in a given site [Angelaccio et al. 2012]. Such solutions generally consist in pre-packaged applications, with few possibilities for the CH experts to customize them according to specific presentation goals addressing specific (groups of) visitors [Petrelli et al. 2013].

Providing personalized visit experiences is a need that emerged in several studies that we performed in the last years in the CH domain [Ardito et al. 2012b; Ardito et al. 2012d; Costabile et al. 2008]. In order to accommodate it, fixed, pre-packaged applications have to be replaced by software systems that flexibly allow domain experts, i.e., CH curators and guides, to configure and customize the applications to be used during the visit. We therefore exploited Web service technology to develop an End-User Development platform that allows domain experts, who are not technology skilled, to extract contents from heterogeneous (personal or third-party) digital sources, and mash them up to compose "on-the-fly" interactive workspaces integrating resources useful for end user's needs in the various contexts in which it is used [Ardito et al. 2014b]. The platform provides a visual paradigm for content extraction and composition. The resulting interactive workspaces can be ubiquitously distributed across different devices, including visitors' personal devices. Various user studies allowed us to assess the usability and ease of use of the composition paradigm with respect to the CH actors' skills and expectations, as well as the capability of the overall framework to assist the production of interactive artefacts that enhance the engagement of groups of visitors [Ardito et al. 2014a].

Following the trend toward a massive use of smart objects for smart space building, we recently extended our platform to flexibly combine the functionality of IoT devices [Desolda et al. 2017a]. We defined a visual design environment where the capabilities exposed by IoT devices (i.e., events and actions) can be combined by means of visual mechanisms that avoid writing code. In this article, we introduce further improvements to characterize the semantics of smart objects and facilitate the definition of their cross interactions. In the extended platform, the result of the composition performed by domain experts is not just a visual workspace helping them present some content to visitors; rather it is the configuration of a *smart visit experience* where the interaction with smart objects mediates the user access to CH content.

CH is watching with interest at the IoT phenomenon. Some works show that the interaction with tangible objects favors emotions and engagement [Not et al. 2017; Petrelli et al. 2013; Petrelli and Lechner 2014]. Indeed, physical manipulation and actions are very effective in conveying information and also improve content appropriation [Manches 2011; Yannier et al. 2016]. In this article, we show how our framework can be fruitfully exploited by CH experts to create smart visit experiences. In particular, we purposely revised the composition paradigm in order to favor the definition of *custom properties* associated to smart objects. Through these additional properties, the designers of the interactive experience can thus make sense of low-level events and actions, by contextualizing the use of smart devices in narrative scenarios supporting personalized fruitions of content. Indeed, IoT hardware platforms (for example Arduino*) are only starting points to create the physical devices, but some efforts are needed to create toolkits that allow the non-technical stakeholders to personalize the behavior and the cross interaction of such objects [Petrelli et al. 2013].

The need for higher-level abstractions is already evident in some works that support CH experts in designing interactive visit experiences based on serious games [Bellotti et al. 2013]. Some proposals adopt ontologies and semantics [Tutenel et al. 2008] to give operational meanings to the objects in the virtual worlds a game consists of. This allows the experts to focus on the specifics of the cultural domain, more than on the technicalities of a virtual word definition [Vanacken et al. 2007]. In [Korzun et al. 2017] the authors propose an IoT system for CH sites where the information about the exhibit is semantically enriched by means of knowledge extracted from online resources and social media. The integrated corpus of knowledge is then exploited for supporting visitors' learning, content construction by museum personnel, and historical analysis by professionals. Similar to this approach, in [Gatto and Pittarello 2014] the authors propose a method to derive annotations for Web-3D educational narratives from a crowdsourcing paradigm. These augmentation processes are in line with our research, which aims to enrich the semantics of digital artifacts to facilitate the activities of smart-visit designers. As we will show in this article, our work focuses on the definition of adequate visual notations, through which the CH professionals themselves can define custom properties that help them make sense of the available smart devices and digital resources.

Before describing our approach, in the rest of this section we discuss some relevant related works. We in particular refer to methodologies and systems that facilitate the adoption of smart objects in CH sites and to EUD approaches that enable the configuration of smart visit experiences by CH professionals.

2.1. IoT Technologies in CH sites

A substantial amount of work has been carried out on how to exploit technologies to offer more engaging experiences of Cultural Heritage [Cabrera et al. 2005; Copeland 2004; Damiano et al. 2013; Lanir et al. 2017; Lanir et al. 2016; Mokatren et al. 2016; Not et al. 1997; Sintoris et al. 2010; Stock and Zancanaro 2007; Wecker et al. 2017]. A wealth of digital content is currently available in online repositories, portals or museum servers. Such content is mainly exploited through static delivery paradigms. Most work is indeed related to the use of Web technologies to provide information about museums, historical sites, events, in some cases creating virtual reality reconstructions of specific exhibitions [Ardito et al. 2007; Bellotti et al. 2013]. Mobile technology has been largely employed to support visits to CH sites since its early stage [Ardito et al.

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* https://www.arduino.cc/

2012c; Hsi and Fait 2005], as well as large screens of different types [Ardito et al. 2015a]. In many cases, visitors are provided with multimedia companions that try to improve the overall visitors' experience using audio, video and textual information [Barbieri et al. 2009; Kuflik et al. 2015]. Some approaches also take into account the needs of people with different expectations and abilities in using mobile devices [Antoniou and Lepouras 2010; Kuflik et al. 2011].

The literature is full of several other contributions. However, the possibility of letting visitors interact with digital content through a physical engagement with the exhibits is still scarcely explored. The interaction with tangible objects supports visitors to put information in context without any effort to interact with apps and touch screens [Risseeuw et al. 2016]. As discussed in [Petrelli et al. 2017] some studies show that mobile devices during the visit attract the visitor's attention on the screen of the device; visitors in some cases ignore the artworks [Vom Lehn and Heath 2003]. Smart objects, instead, favor the so-called *tangible thinking*, that is the ability to think by means of the physical manipulation of objects augmented with digital information [Ishii and Ullmer 1997]. Also, the use of such new tools can favor a "non-linear narration" [Casillo et al. 2016], in which narrative itineraries can be contextualized to the environment and to the user interaction with smart devices within physical places. The visit experience can be thus personalized to the way users react to some stimuli or act on some content.

In the last years, some works have proposed solutions to install and configure IoT devices into CH sites. Some of them deal with technology-related aspects. For example in [Chianese and Piccialli 2014], authors discuss how to design an information system able to capture data from IoT devices to introduce smartness in indoor environments like museums or art exhibitions. In [Piccialli and Chianese 2017a; Piccialli and Chianese 2017b] the authors illustrate how IoT systems can be exploited to monitor context parameters (e.g., visitor location, visited rooms in a museum). This enables tracing the evolution of a visit in a CH site; visitors can thus be provided with personalized recommendations by invoking proximity-based, multimedia services. In [Mighali et al. 2015] the authors then describe how to design a processing server for providing CH visitors with Web services that seamlessly combine IoT devices, mobile and wearable devices and enable the access to digital content available on the cloud. All these works propose interesting solutions for installing smart devices and related services within CH sites. However, they do not consider at all how to facilitate the definition of smart visit experiences by CH curators; in other words, they concentrate on the technology infrastructure while neglecting how to make sense of such technology.

In [Console et al. 2013], authors define an interaction model with tangible objects that aims to facilitate the exploration of a network of objects in the food domain. They in particular propose *WantEat*, an intelligent mobile application through which everyday objects representing gastronomic items (e.g., food products, market stalls, restaurants, and shops) can be enabled to communicate with users and to create social relationships with users and other objects. By means of the mobile app, users get in touch with smart objects by taking a picture of a product label or by identifying the geo-location of the users and of the objects around them. Through a personalized and serendipitous interaction with networked things, the app shows content about the place reached by the users and its history. The app also establishes a social dimension by allowing users to see other users' comment and to leave their own comments. This approach is very interesting, especially because the social dimension enriches the content of the territory by means of users' personal experiences. As demonstrated by an evaluation study [Rapp et al. 2016], the approach is effective in promoting the discovery of new items and this helps users identify and follow a path for content fruition. However, the users interact mainly through the mobile app, while smart objects exclusively play the role of proxies for geo-localizing the visitors and selecting the proper content to be displayed by the mobile app. Smart objects do not expose any capability to actively produce events or enact actions, neither the possibility to be manipulated by visitors to activate state changes in the environment. We believe that direct interaction with tangible objects would increase the user engagement. Moreover, the proposed mobile app is pre-packaged and cannot be configured flexibly to respond to varying requirements that might occur within specific visit experiences.

2.2. Combining EUD and IoT for defining smart visit experiences

Very few contributions in the literature address the possibility of enabling CH experts to shape up smart visit experiences. One prominent approach is the one proposed by the meSch project, which aims to enable CH professionals to create tangible smart exhibits enriched by digital content [Petrelli and Lechner 2014; Petrelli et al. 2017]. The peculiarity of the meSch approach is that it does not require IoT-related technical knowledge: the platform offers an authoring tool where physical/digital narratives can be easily created by composing digital content and physical artefact behaviors [Bellotti et al. 2013; Risseeuw et al. 2016]. The meSch approach is indeed grounded on principles of co-design and on a Do-It-Yourself philosophy, which involve designers, developers and CH stakeholders in the design of the visit experience. This work is very interesting also because of the large experimentation involving CH curators. However, the configuration of a smart object is limited to specifying which content has to be displayed by an interactive case when the users place on it specific objects (i.e., replicas of museum objects). We believe that the combined use of different smart devices could be fruitful in several situations, especially when the visit experience consists of enjoyable tasks so that, through playing, visitors acquire as much information as possible about the target topic [Bellotti et al. 2013]. In this case, tools must facilitate the inclusion of multiple physical objects and IoT devices, as well as the definition of expressive rules to combine their behavior.

In [Díaz et al. 2015] the authors deal with the problem of identifying what elements give value to experiences with smart objects within a cultural heritage site, and how these experiences can be supported by IoT. They propose CODICE, a tool enabling co-design by multidisciplinary teams made up of designers, developers, CH professionals and end users. CODICE helps such stakeholders envision usage scenarios and prototypes involving smart objects. One of the outcomes of the co-design activities is the definition of *prototypes*, i.e., specifications of the smart objects that will be implemented to shape up the visit experience. This approach is valuable for envisioning usage scenarios that can really motivate visitors; it is important in the very early design phases, when it is necessary to identify strategies to adopt smart objects within CH sites. However, once the usage scenarios are identified and the technology infrastructure is in place, the approach does not offer any further support for the configuration of prototypes by CH professionals.

The EUD approach presented in this article aims to enable CH stakeholders to configure the behavior of IoT devices available in the CH site, and easily modify it if needed in specific situations. The paradigm for the creation of smart visit experiences is based on our previous work [Desolda et al. 2017a], which focuses on the definition of usable, effective and efficient composition metaphors for Task-Automation Systems (TASs) [Coronado and Iglesias 2016]. We identified visual abstractions that enable even non-programmers to define Event-Condition-Action (ECA) rules that automatically detect events generated by some devices and actuate some actions on the same or on different devices in order to determine their behavior. We implemented the related visual mechanisms in the EFESTO-5W platform [Desolda et al. 2017a]. With respect to other TASs, our approach promotes a richer set of high-level abstractions and operators to define rules and a visual notation that, despite the intrinsic complexity related to managing events and actions, is affordable by non-programmers [Desolda et al. 2017b]. In the following sections we will show how further abstractions and visual mechanisms can help designers contextualize ECA rules with respect to the content and learning goals of narratives for smart visit experiences. Differently from other scenarios for smart object configuration, smart visit experiences may consist of the incremental activation of different rules that progressively involve new objects and that in the end lead the final user to discover new content. In addition, smart visits to CH sites require, more than other domains and smart-experience scenarios, to augment the semantics of smart objects. This is because smart visits have an intrinsic richness of content that cannot be conveyed to visitors by simply considering technical properties of smart objects.

The new abstractions introduced by our approach therefore focus on expressing properties that can help define relations among different objects and conditions on rule activation, making explicit the role of the objects themselves not as isolated elements to be programmed, rather as components of an articulated scenario related to the discovery of some content. The additional semantics can make it easier for smart-experience designers to identify and manage the different elements to be considered and set up when defining cross-interactions of multiple devices. In the rest of the article, we specifically focus on CH scenarios and smart visits. However, our approach can be adopted in any other domain where non-technical stakeholders need to create smart experiences.

3. Elicitation study

The main goal of our research is to provide end users, who do not have any skills in programming, with interactive tools to create smart experiences by managing ecosystems of interoperable smart objects. The paradigm for ECA rule specification implemented in the EFESTO-5W platform was considered usable and useful in scenarios where the rules defined by end users are strictly related to the low-level events and actions exposed by the smart devices. This is, for example, the case of home automation (a domain in which we conducted our previous studies [Desolda et al. 2017a]), where rules especially refer to the intrinsic semantics of data sensed by devices (e.g., room temperature) and of the actions a device can enact (e.g., turn on the heat). In addition, end users could define a number of rules that do not necessarily show relations among them, or that do not need to be put in context in respect to a given goal.

In relation to the definition of smart experiences, we realized that some extensions are needed, in order to: *i)* contextualize the use of smart objects and related synchronization rules in respect to a content characterizing the experience and, *ii)* identify and express possible interactions among objects and rules in relation to this content. Indeed, smart visit experiences are characterized by the provision of content in a narrative. Thus, they may consist of the progressive activation of different rules and evolving states of the environment, which lead to the discovery of content for the achievement of some learning goals. If a layer of additional properties related to the CH site content is provided, ECA rules and the evolving states of the environment could be easily identified and managed by CH professionals.

In other words, we need to introduce mechanisms through which the designer of the smart experience can make sense of the capabilities offered by the technology infrastructure. This is in line with the goal of the Transformative User Experience (TUX) [Ardito et al. 2015b; Latzina and Beringer 2012], a recently proposed framework for information access and manipulation that aims to natively support users in a variety of spontaneously self-defined task flows. TUX responds to the users' situational needs by enabling user interaction with special *containers* that "group" information items that are transformed according to the semantics of the task they refer to. TUX indeed allows the user, who wants to access some information, to confer different capabilities to data by simply moving data across different containers. The effect is to progressively augment the meaning and the set of operations of the original data, depending on the semantics assigned to the specific containers through which data are moved. The involved objects are incrementally extended with new attributes or operations that make sense for the current user tasks. For example, given a list of objects rediscovered in an archaeological area, the user could move the object representation (e.g., a picture) inside a *Locating Container*. As a result, the selected object is shown as a pin on the map in the position where it was rediscovered. The path from the current user location to the rediscovery place is also automatically calculated and depicted on the map. The user governs the transitions among different containers, depending on the current usage situation and on the functionality (e.g., data manipulations) needed to further proceed with his/her task.

Inspired by this framework, we promote the notion of *custom attributes* as conceptual tools that can allow designers to characterize the basic elements of a smart experience (i.e., smart objects and rules) with a semantics related to the content to be conveyed during the smart experience. As we will show in Section 5.5, we also propose a visual environment and a composition paradigm where specific containers serve the purpose of defining custom attributes and grouping objects sharing the same attribute values.

The rest of this section reports on a study to investigate the validity of custom attributes as conceptual tools to augment the semantics of the resources a smart experience is based on. In particular, the study wanted to investigate the usefulness of adding additional semantics as a way to transform smart objects from devices generating low-level signals to objects contributing to the visit narrative by means of their content-related properties. At this stage, the study did not aim to validate the interactive visual paradigm that we implemented in our composition platform to define custom attributes.

3.1. Research Questions

To assess if adding semantics to smart objects and rules is feasible by CH professionals and can be considered a solution to facilitate the definition of smart visit experiences, we conducted a study involving some curators and guides of CH sites. The research questions that guided the study were:

RQ1) Is it feasible by CH professionals to identify *pertinent smart objects* to be used during the visit and related *custom attributes* that can express the semantics of the smart objects in use?

RQ2) Can *custom attributes facilitate the definition of rules* governing the behavior of the smart objects?

During the study, we observed and collected hints on how curators and guides of CH sites would define smart visit experiences. First, participants were requested to design a visit experience that included smart objects. Then, they had to work on assigning semantics to the objects and services involved in the designed scenario with the aim of facilitating the creation of rules governing the cross-interaction among the different components of the smart visit experience. Finally, they had to define, very informally, the rules for controlling the component behavior.

3.2. Participants

The study involved 6 professional guides (3 females), aged between 29-55 years ($\bar{x}$ = 38.5, SD = 9.26). The participants had a long experience in performing guided visits in archaeological parks (n = 1), Natural Science museums (n = 1) and wildlife parks (n = 4). All of them were familiar with the use of mobile devices, but had no experience with managing IoT devices.

3.3. Procedure

The study was managed by two Human-Computer Interaction researchers, who met the guides at their own offices. The archaeological park guide and the Natural Science museum guides performed the study individually, while the wildlife park guides participated in group. The study procedure was the same in the three meetings. One of the two researchers acted as facilitator. The second researcher took notes. Each design session was also video-taped.

In the introductory session, the facilitator gave a 10-minute presentation to the participants, by illustrating daily-life situations in which IoT technology can be employed, e.g., controlling home appliances according to user's actions or position, or events happening on social networks. Two examples were illustrated to participants: 1) "As soon as the garage door is opened, switch-off the alarm, open the rolling-up shutters and switch-on the air conditioning", and 2) "Turn blue the smart light if somebody tags me on Facebook". In order to avoid any bias in the participants' proposals, possible examples referring to visits to CH sites were not illustrated.

Afterwards, the design session started. Each participant was provided with blank paper sheets and markers for sketching their proposals. The facilitator asked the participant(s) to reason about and discuss a scenario in which the visit is supported by ICT and IoT technology. A short task-scenario was communicated, in order to facilitate the participant's initial reasoning. Each scenario is described in the following.

1. Proposed to the archeological park guide: *Rocco is a guide of the archeological park of Egnathia, an ancient Roman city in Southern Italy. He often organizes guided tours inside the park for groups of 20 visitors. Rocco usually adopts a tablet to show pictures or 3D models of the ruin reconstructions or, especially when visitors are pupils, organizes games similar to a treasure hunt. Rocco would improve the visit effectiveness by proposing a game, which exploits the opportunities offered by the recent IoT technology.*

2. Proposed to the Natural Science museum guide: *Lisa is a guide at the museum of the Natural Science department of the University of Bari. Most of the visitors are pupils, who come to the museum during school excursions. The countless exhibitions available in the museum are safeguarded in display cases and cannot be touched by visitors, thus hampering her possibilities of offering a more engaging visit experience. Lisa would change this situation with the help of the technology.*

3. Proposed to the group of the wildlife park guides: *Mario is a guide of the MUSA, a museum recently built by WWF in the Torre Guaceto oasis, a wildlife park in Southern Italy, next to the Adriatic sea. It's Summer time and many families conclude their day at the beach by participating in the guided tour Mario carries out at sunset. Unfortunately, most of the bird species that live in the park have migrated to North Europe and will come back at the beginning of Fall. Mario wants to exploit ICT and IoT technology, in order to engage visitors during the outdoor visit and stimulate them to continue the experience indoor, i.e. in the museum at the Torre Guaceto park*.

Starting from such scenarios, the participants were stimulated to iteratively focus on four aspects: 1) design of the smart visit experience narrative; 2) identification of a set of smart objects involved in the smart experience; 3) characterization of the identified smart objects by means of custom attributes; 4) elicitation of the role played by each smart object in the narrative; 5) definition, in natural language, of the rules that determine the behavior of the smart objects. The participants were repeatedly invited to leave out possible technical difficulties or limitations. Furthermore, in order to evaluate the intuitiveness of our approach, they were not introduced to the composition paradigm and its characterizing concepts.

At the end of the design session, the participants filled out an online questionnaire composed of 16 questions. Thirteen closed questions aimed to collect participants' demographic data and their expertise with programming, mobile devices, smart objects and Web services. One closed question investigated participants' understanding of and comfort with study procedure and proposed tasks. The last two open questions addressed the pros and cons of the ideas they suggested during the study.

3.4. Collected data

During the study the following data were collected: 1) the notes taken by the researchers in the study sessions; 2) the video recorded during the sessions; 3) the sketches drawn during the sessions; 4) the paper sheets on which the guides outlined the scenario visit narrative, the list of smart objects with their custom attributes and their role in a tabular format (see Tables 1-3), and the rules controlling the objects; 5) the answers participants gave to the questionnaire. The tabular format for describing the smart-object properties was adopted by the guides as they followed some examples, related to other domains, that the researchers illustrated during the introductory session.

The set of collected notes was substantially extended by video-analysis. The videos were independently transcribed by each of the two researchers involved in the study, literally noting down all intelligible speech. Then, together they analyzed the transcripts and found out an initial agreement value of 81%. The remaining 19% of discrepancies were solved by discussion. The transcribed data and the answers to the two questionnaire open questions were annotated by using different colored markers to categorize the content under emerging themes. Then all the data were grouped, through the affinity diagram technique proposed in [Rogers et al. 2015], under main themes related to advantages and disadvantages of using the proposed solutions.

3.5. Results of scenario design

Three visit scenarios were elaborated by the participants, one for each CH site type in which the professional guides had specific experience. For each scenario, in the following we report, in the format defined by the participants: the interactive experience narrative, the list of smart objects together with their attributes and semantics, and the rules for defining their behavior.

Scenario 1 - A game in the archaeological park of Egnathia

Rocco would improve the visit efficacy by proposing a serious game to be played in the archeological park of Egnathia. Visitors are organized in teams and provided with a deck of smart cards, each depicting something related to Egnathia (e.g., tools, places, monuments, daily-life scenes). Due to the relations between Egnathia ruins and the Roman Empire, Rocco wants to use also a reproduction of the "Mouth of Truth"[†]*. During the tour, Rocco stops in some point of interests, illustrates their history and asks teams to give an answer to his questions. Instead of their hands, visitors insert in the "Mouth of Truth" the card that represents their answer. If the answer is correct, the "Mouth of Truth" eyes blink green and the team current score is increased. At the end of the tour, the team with the highest score wins a park souvenir.*

The archaeological park guide reported that two types of smart objects are needed in his scenario, i.e., the smart cards given to teams of players and a device carried by the guide, i.e., the Mouth of Truth. As described in Table 1, the guide also identified that each type of object is characterized by the attributes in the "Custom Attribute name" column and provided examples of possible values of the attribute as in the "Attribute value example" column. Finally, he provided, in the "Attribute explanation" column, a description of the semantics of the attribute in the designed scenario.

[†] The *Mouth of Truth* is a marble mask placed in Rome, Italy. According to the legend, the person who tells the truth can put safely the hand in the mouth, while the person who lies will have the hand cut by the Mouth.

Table 1. Scenario objects and their custom attributes proposed by the archaeological park guide.

Scenario object	**Custom Attribute name**	**Custom Attribute value examples**	**Custom Attribute explanation**
Team's Card	Card name	Amphora – Coin – Music instrument	Name assigned to the card. Usually it refers to the object(s) represented by the card
	Discovery Place	Kiln – Basilica – Temple	Place where the object was rediscovered
	Historical Age	Roman time – Messapian time	The age the object belongs to
	Team	Team 1 – Team 2 – Team 3	The team the card belongs to
	Points	3 – 5 – 7	Number of points gained by the team if the card is used correctly
Guide's Device	Device name	Mouth of Truth	Name assigned to the device carried by the guide
	Sensible Position	Close to the Kiln – Inside the Basilica	Place to be recognized during the visit
	Location Age	Roman time – Messapian time	Historical age of the place where the device is currently located
	Modality	Location Matching – Age Matching	Modality in which the device checks : i) if its *Sensible Position* matches the *Discovery Place* attribute of the cards used by visitors or ii) if the *Historical Age* of the device position matches the *Historical Age* of the visitor's card

Finally, the guide defined the following rules, as the most representatives among those needed for his scenario:

1. "When a team member puts a card in the guide's device and the device *Modality* is *Location matching*, if the *Discovery Place* of the card matches the device *Sensible Position*, then assign the card *Points* to that team".
2. "When a team member puts a card in the guide's device and the device *Modality* is *Age Matching*, if the card *Historical Age* matches the device *Location Age*, then assign the card *Points* to that team".

Scenario 2 - A game in the Natural Science museum

Lisa has recently received a grant for renovating the museum where she works. She decides to devote part of the grant for setting up a large exhibition room in which different biomes[‡] *are recreated. A room area will propose a portion of a Mediterranean scrub forest, another area a dissected portion of the Atlantic Ocean coast (from the cliff to the ocean floor), and a third area a mountain scene. Each biome will be instrumented with smart devices to enable a kind of treasure hunt game, played by group of visitors after her explanation on the different biomes. Each group will be assigned a specific biome, a set of smart objects (e.g., cards representing flora and fauna elements) and a tablet through*

[‡]*Biome* is a complex biotic community characterized by distinctive plant and animal species and maintained under the climatic conditions of the region.

which the various quests are communicated. The main goal of the game is to identify the right association between the smart objects and their position in the biome. For example, on the basis of the riddles received through the tablet device, the players have to identify that their target is the card representing the owl and that it has to be placed on the branches of a tree. At the end of the game, a short video-documentary about the biome is proposed through the tablet display.

The Natural Science museum guide identified the objects reported in Table 2: a set of cards and a mobile device assigned to each team, a mobile device for the guide, and a set of unmovable sensors placed in the biome reconstructions.

Table 2. Scenario objects and their custom attributes proposed by the Natural Science museum guide.

Scenario object	Custom Attribute name	Custom Attribute value examples	Custom Attribute explanation
Team's Card	Card name	Owl – Buzzard	Name assigned to the card. Usually it refers to the object(s) represented by the card
	Biome	Mediterranean scrub forest – Atlantic Ocean coast	It is the place where the object can be rediscovered
	Position	Tree branch – Ground	The specific position in the biome in which the object is placed
	Team	Team 1 – Team 2	The team a card belongs to
	Points	3 – 4 – 5	Number of points gained by the team if the card is used correctly
Team's Device	Device name	Tablet Group A – Tablet Group B	Name assigned to the device carried by a group of players
	Sensible Position	Mediterranean scrub forest – Atlantic Ocean coast	Place to be recognized during the visit
	Modality	Communicating quest – Playing multimedia	Modality in which the device communicates the current quest to the players or displays a multimedia
Guide's Device	Device name	Guide's device	Name assigned to the device carried by the guide
	Sensible Position	Mediterranean scrub forest – Atlantic Ocean coast	Place to be recognized during the visit
	Modality	Location Matching	Modality in which the device checks if its current position matches the position indicated in the place attributes of the card used
Sensor	Device name	Tree branch – Beach – Seabed	Name assigned to the RFID readers installed in the park
	Place	Tree branch – Beach – Seabed	Place where the device is currently located
	Modality	Card detecting	Modality in which the device detects the card put in contact with it

As example of rules, the Natural Science museum guide defined the following rules:

1. "When a team member puts a card in contact with the guide's device, if the *Position* associated to the card matches the Guide's Device *Sensible Position*, then assign the card *Points* to that team

and display the next *Quest* on the team's mobile device".
2. "If all the *Quests* have been concluded, then play a video-documentary on the team's mobile device".

Scenario 3 - Visiting the Torre Guaceto wildlife park

Mario organizes tours inside the Torre Guaceto park. He decides to devote part of the MUSA budget to innovative features for improving the visits. Mario organizes the visit in two phases. First, an outdoor exploration of the park, where visitors are equipped with the "magical mini-sphere", a device to measure environmental parameters by performing funny activities. The second phase is performed indoor and aims to simulate the effects of bad human behaviors on the environment. During the first phase, visitors can use a fishing pole to throw the magical mini-sphere in the canal and measure some water parameters. Alternatively, visitors can measure air parameters by attaching the sphere to a kite that they have to make fly. The sphere is remotely controlled by a tablet provided to visitors. Every time they have to catch a parameter, they select the sphere modality (water, air, ground) and then they tap the button "Measure". After gathering various environmental parameters, visitors go inside the MUSA. Here they can interact with a large multi-touch display that shows the values they measured on a reproduction of the Torre Guaceto oasis. The multi-touch application allows visitors to simulate long-term human dangerous behaviors, for example growing of garbage on the ground or polluting liquids in the canal, and the consequence in term of parameter changes and flora and fauna diseases.

The wildlife park guides identified the following objects, as reported in Table 3: a sensor to measure water, air and ground parameters, and a mobile device.

Table 3. Scenario objects and their custom attributes proposed by the wildlife park guides.

Scenario object	**Custom Attribute name**	**Custom Attribute value examples**	**Custom Attribute explanation**
Sensor	Name	Magical ball	Name assigned to the device used for measuring environmental parameters
	Modality	Air, Water, Ground	Modality in which the device measure a specific type of parameters
	Sensible Position	Canal, Lake, forest	Places to be identified during the visit
Mobile Device	Device name	Visitor's tablet	Name assigned to the device carried by the visitors
	Modality	Air, Water, Ground	Measure modality; based on it the mobile device controls proper sensors measuring a specific type of parameters

Finally, the guides defined the following rule:
1. "If a visitor sets the mobile device in a *Modality* and taps the *Measure* button, then switch the Sensor in the corresponding *Modality* and save the measured values".

3.6. Results from notes and online questionnaire data

The online questionnaires referred to demographic data and to the experience in programming and using IT technology. The analysis of the collected answers provided the participants' characterization already reported in Section 3.2. The understanding of and the comfort with study procedure and proposed tasks were rated 2.5 out of 7 (lowest is better).

The thematic analysis carried out on the transcribed data and the answers to the two open questions allowed us to identify themes related to advantages and disadvantages of using the proposed solutions. Regarding the advantages, participants think that *i)* a non-expert has a high-autonomy in creating complex technical solutions; *ii)* the resulting visit experiences can be more engaging and effective; *iii)* a smart experience can be created, simulated, improved and customized by CH experts without the need to stay in the site. Concerning the disadvantages, some participants commented on their scarce knowledge about smart object potentialities. This could be a problem when they have to identify which smart objects have to be included in the smart experience they are designing.

4. Elements of a Smart Experience

Based on what we observed in the study reported in the previous section, we now illustrate the abstractions that can lead to a composition paradigm that would enable domain experts (i.e., the end users of our EUD platform) to define *smart experiences*. Figure 1 schematically represents the main conceptual elements and the way they relate to each other. First of all, the smart experience requires some *resources*: *Smart Objects* or *Web Services*. In addition to the elements emerged in the scenarios described in the previous section, we also consider Web services as software engines that can offer access to complementary data and functionality needed to manage the logic beyond the cross interaction of smart objects. For example, even if not explicitly highlighted by the guides taking part to the study, a *Game Engine* Web service is needed to manage the score assignment to the different teams during the game or to declare the winner team in the end. As explained later in the article (see Section 5), these computational elements are in general identified and managed with the help of expert designers and developers who have an adequate technical background. We indeed promote a methodological framework where different stakeholders, with different expertise, concur to the definition of the elements of the smart experience.

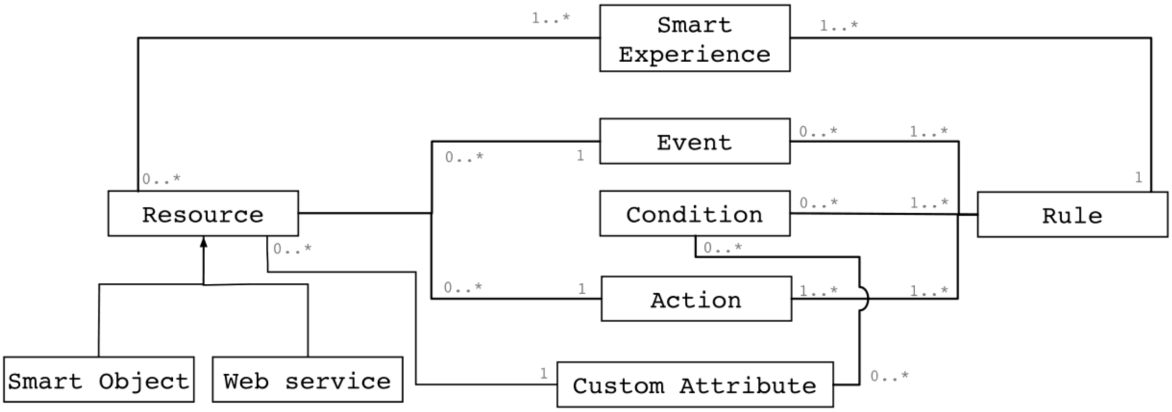

Figure 1. A schematic representation of the main conceptual elements to compose smart experiences.

Any resource, being it a smart object or a Web service, has a set of associated *events* that the resource is able to detect and a set of *actions* it is able to execute. Events and actions can refer to the physical word where the smart experience takes place, or to data and software functions the smart experience refers to.

Characterizing resources by means of events and actions enables adopting an event-driven logic for cross-resource interaction: the detection of events by some resources enacts the execution of some actions by the same or by different resources. Events are queued as soon as they are detected and consumed as soon as the conditions for action activation are satisfied. This is what we call *synchronized behavior*, which we consider a fundamental feature for the creation of smart experiences. Therefore, we consider the *smart experience* as a set of *ECA rules* that describe the synchronized behavior of some involved *resources*.

It is worth noting that we focus on situations where smart-experience participants could also be source of events and actions. We assume that user events and actions be mediated by smart objects: user events are captured by some devices (that can be installed in the environment or embedded within tangible objects); user actions can be actuated by means of devices (e.g., the user provides an answer to the CH-guide question by positioning an RFID card close to the guide's device).

Let us now define in more details the concepts represented in Figure 1. The provided examples refer to the Scenario 1 reported in Section 3.5 (Rocco's scenario).

Definition 1: Smart Experience. It is the combination of behaviors of different *resources* that the end users define by means of ECA *rules*. More specifically, a Smart Experience, *se*, can be considered as a set of rules that synchronize events and actions exposed by some involved resources. Thus, an *se* is a pair:

$$se = \langle Re, Ru \rangle$$

where *Re* is the set of involved resources and *Ru* is a set of rules that synchronize the behavior of resources belonging to *Re*. Each rule can be defined on top of one or more resources.

Definition 2. Resource. Resources can be both *smart objects* and *Web services*. Smart objects are the logical representation of a physical device used in the real world. Web services are software resources that can help govern the cross-interaction of smart objects by capturing new states or by determining new states of the smart experience. For example, in the Rocco's scenario, the involved resources include two smart objects, *Team's Card* and *Guide's Device.* A Web service, *Game Engine,* is also exploited as additional resource to control the game dynamics, for example to update team scores.

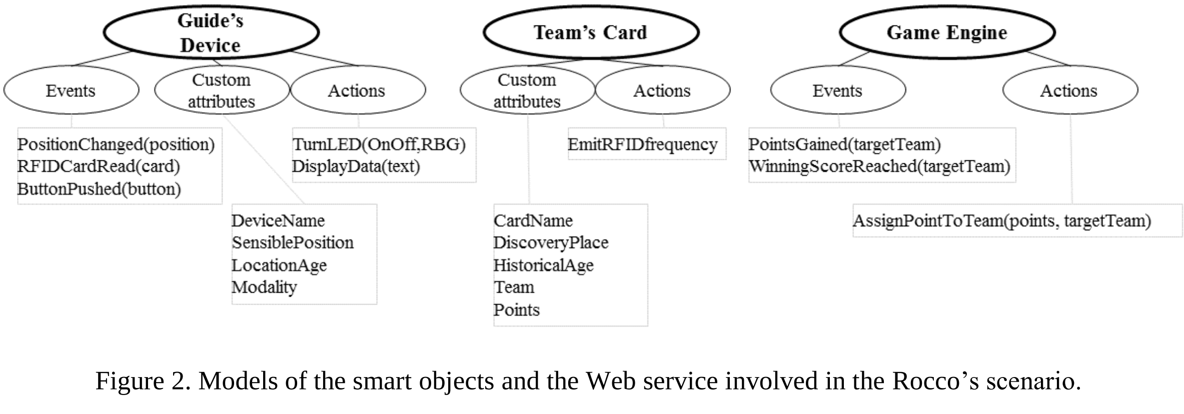

Figure 2. Models of the smart objects and the Web service involved in the Rocco's scenario.

Resources for smart experiences are dynamic components, and it must be possible to synchronize their behavior by means of an event-driven logic. Their semantic can be also extended by means of *Custom*

Attributes. Therefore, a resource can be characterized as:

$$re = <E, A, CA>$$

where *E* is the set of *events*, *A* is the set of *actions* and *CA* is the set of *custom attributes*.

Figure 2 reports the elements of the three sets for the two smart objects in the Rocco's scenario (i.e., the *Guide's Device* and the *Team's Card*) and for the *Game Engine* Web service. We now define in more details *events, actions* and *custom attributes*.

Definition 3. Event. It represents a state change that a resource is able to detect. *Event parameters* express the new values sensed for the variable the event refers to, and can be exploited to express conditions over rule activation. State changes generating events can occur in data produced by the surrounding environment (e.g., the temperature in a room), or they can also be generated by participants' actions within the environment, which are mediated (i.e., captured) by smart objects. For example, the event *PositionChanged(position)* exposed by the *Guide's Device* smart object (see Figure 2) is generated when the visitor, and the guide with his device, move to a given position in the site. The new position is gathered by the devices and made available to the system. Similarly, the events *RFIDCardRead(card)* and *ButtonPushed(button)* occur when visitors respectively put a given *Card* close to the *Guide's Device* and when they press the *button* of the device.

State changes can also refer to data retrieved and managed through Web services. For example, the events exposed by the *GameEngine* Web service are *PointsGained(targetTeam)* and *WinningScoreReached*(*targetTeam).* The two events are generated by changes in the score assigned to a team, represented by the parameter *targetTeam*, and when the team reaches a score that makes it win the game. Finally, there might be resources that are not able to sense events. This is the case of the *Team's Card* device, as RFID cards for their nature are not able to sense any event; rather their RFID frequency can be detected by a reader as the one embedded within the *Guide's Device*.

Definition 4. Action. As a reaction to the sensed events, an action refers to a function that a smart object can execute through its actuators or that a Web service can perform through its operations. Actions therefore produce state changes at different levels. They may have effects on the environment where the experience takes place (e.g., the lights of a room are switched on), or on smart objects manipulated by the final users. For example, the actions for the *Guide's Device* reported in Figure 2 (*TurnLED(OnOff, RGB)* and *DisplayData(text)*) make the object blink its LED and display a text reporting the score reached by a team. Through service operations, actions might change the value of some variables related to the experience logic. For example, the *Game Engine* Web service exposes the action *AssignPointToTeam(points, targetTeam)* that changes the value of the points gained by a given team.

Definition 5. Custom Attribute. It is the most characterizing element of our approach since it allows smart experience designers to extend resources with a semantics related to the content to be conveyed to the experience beneficiaries. These properties can be related to or independent from events and actions.

Each custom attribute, *ca*, can be defined as:

$$ca = <name, V_{CA} = \{v_1, v_2, \ldots, v_n\}>$$

to indicate that its definition consists in specifying the *values* v_i that the *ca* represented by a given *name* can hold in the context of the smart experience.

The attributes specified in Table 1 for the Rocco's scenario correspond to custom attributes that augment the semantics of the involved smart objects. The criterion for choosing a specific attribute to augment resource semantics is generally related to the cognitive target to be proposed to the visitor [Bellotti et al. 2013]. For example, some attributes can help contextualize an action with respect to the exhibited content, or can serve as mechanisms for assessing if a learning goal has been reached. In our reference scenario, Rocco associates a *Name* to the cards given to the visitors ("amphora", "coin", "musical instrument"), to distinguish among the different objects the cards could refer to. He then associates a *Historical Age* and a *Discovery Position* to each card as these attributes are useful to define the game dynamics, e.g., to identify whether, by means of the cards, the teams are giving the right answers to the Rocco's quizzes about the age and the discovery place of an object. Every custom attribute is in the end a means for representing explicitly some knowledge about the CH site and the smart visit experience.

Assigning a custom attribute *ca* to a smart object *so* then consists in specifying the values that make sense for *ca* in relation to the use of *so* in a given smart experience. In other words, the association produces the annotation:

$$ann = <ca, v, so> \mid ca \in CA, v \in V_{CA}, so \in Re$$

meaning that *so* is provided with the attribute *ca* holding the *v* value. As a result, *ca* becomes one attribute exposed by the smart object *so*, which: *i)* can be exploited at design time to define conditions within ECA rules and *ii)* can be evaluated during the execution of the smart experience to assess whether *so* reached some sensible states. For example, in our reference scenario, Rocco annotates the *Card* objects with the attribute *HistoricalAge*, and he associates different values to the different cards, thus creating triples like <*HistoricalAge, Roman time*, team's card 1>, < *HistoricalAge, Roman time*, team's card 2>, < *HistoricalAge, Messapian time*, team's card 3>. Using these attributes, some conditions during the visit execution will help assess whether the visitors are using the right card to answer questions on the historical age.

Definition 6: Rule. A rule combines *events* and *actions* exposed by the involved resources plus *conditions* that can constrain the activation of the rule. It is a synchronization mechanism among different resources that users define according to an event-driven integration logic. In general, a rule expresses that, *on* events triggered on one or more resources, *if* specific conditions are satisfied, *then* actions are executed by the same or different resources.

Thus, a rule can be formalized as the following triplet:

$$ru = <E_{ru}, C_{ru}, A_{ru}>$$

where:

- E_{ru} is a logic expression that captures the occurrence of *events* exposed by some involved resource.
- C_{ru} is a logic expression that combines *conditions* over event parameters and temporal and spatial constraints. Given our characterization of smart objects, conditions can also have as arguments *Custom Attributes* exposed by resources. A rule is enacted only if C_{ru} is true.
- A_{ru} is any logic expression that combines actions exposed by the involved resources [Desolda et al. 2017a; Desolda et al. 2017c].

According to this definition, the rules of the Rocco's scenario become:

$\mathbf{ru_1}$ = $E_{\mathbf{ru1}}$ = <GuideDevice.*RFIDCardRead*>,

$C_{\mathbf{ru1}}$ = <(GuideDevice.*Modality* is equal to *LocationMatching*) AND

(GuideDevice.*SensiblePosition* is equal to TeamCard.*DiscoveryPlace*)>,

$A_{\mathbf{ru1}}$ = <GameEngine.*AssignPointToTeam(RFIDCard.Points, RFIDCard.Team)*>

ru$_{\mathbf{2}}$ = <$E_{\mathbf{ru2}}$ = <GuideDevice.*RFIDCardRead*>,

$C_{\mathbf{ru2}}$ = <(GuideDevice.*Modality* is equal to *Age*) AND

(GuideDevice.*LocationAge* is equal to TeamCard.*HistoricalAge*)>,

$A_{\mathbf{ru2}}$ = < GameEngine.*AssignPointToTeam(RFIDCard.Points, RFIDCard.Team*)>

5. Enabling the Definition of Smart Experiences

In this section, we describe all the activities to be performed in order to enable a CH professional to create a smart experience. A case study, in which a professional guide called Rocco creates the smart experience described in “Scenario 1 - A game in the archaeological park of Egnathia” is considered. Overall, he needs to create the smart experience resources and then configure and synchronize their behavior using the EFESTO-SE (EFESTO for Smart Experiences) platform. EFESTO-SE implements the model described in the previous section as it offers visual constructs that correspond to the elements of the model. The use of visual constructs allows the end users to define rules that are automatically translated into running code handling rule execution. On purpose, the prototype name recalls two previous platforms, EFESTO and EFESTO-5W, that implemented EUD paradigms for service mashup [Desolda et al. 2016] and smart object composition [Desolda et al. 2017a], respectively. EFESTO-SE is a further effort in the direction of enabling end users, not familiar with programming, to create their own interactive tools, thus becoming smart experience designers.

Before illustrating the steps for creating the smart experience, it is worth describing the methodological framework implemented in EFESTO-SE.

5.1. Methodological framework

The entire process for defining a smart experience is framed by a three-layer meta-design framework that we developed for the first prototype of the EFESTO platform [Ardito et al. 2014b], and that is here extended for developing smart experiences (see Figure 3). Meta design means “design for designers”; it is a new design paradigm according to which software engineers, i.e. professional developers, do not design a unique final system, but they design software environments through which domain and/or technology experts customize the system for its initial use by the end users [Fischer et al. 2004]. At each layer of our model, meta-design activities are performed, or a mix of design and use activities, depending on the different stakeholders involved. Each stakeholder contributes to these activities with her/his own competencies in the domain or the technology, thus alleviating the lack of expertise by the others. Indeed, at the *top-layer* of Figure 3, professional developers create or modify the software environments that require IT skills. In the *middle-layer*, professional developers (e.g., makers[§] or IT experts) and domain experts (e.g., CH curators) collaborate to customize the general-purpose platform by 1) selecting, from what is already available in the platform, or creating from scratch the resources of the smart experience to be developed, and 2) configuring such

[§] Makers: digital artisans working in makerspaces or FabLabs, i.e. small workshops that offer customized digital manufacturing services.

resources so that the overall system can exploit them. Such collaboration is essential for a successful customization that prepares the platform for the use in a given domain. For example, with reference to the results of the elicitation study (see Section 3.6), it can help CH guides understand exactly what behavior the smart objects can actually expose. Expert developers can then give support for implementing them.

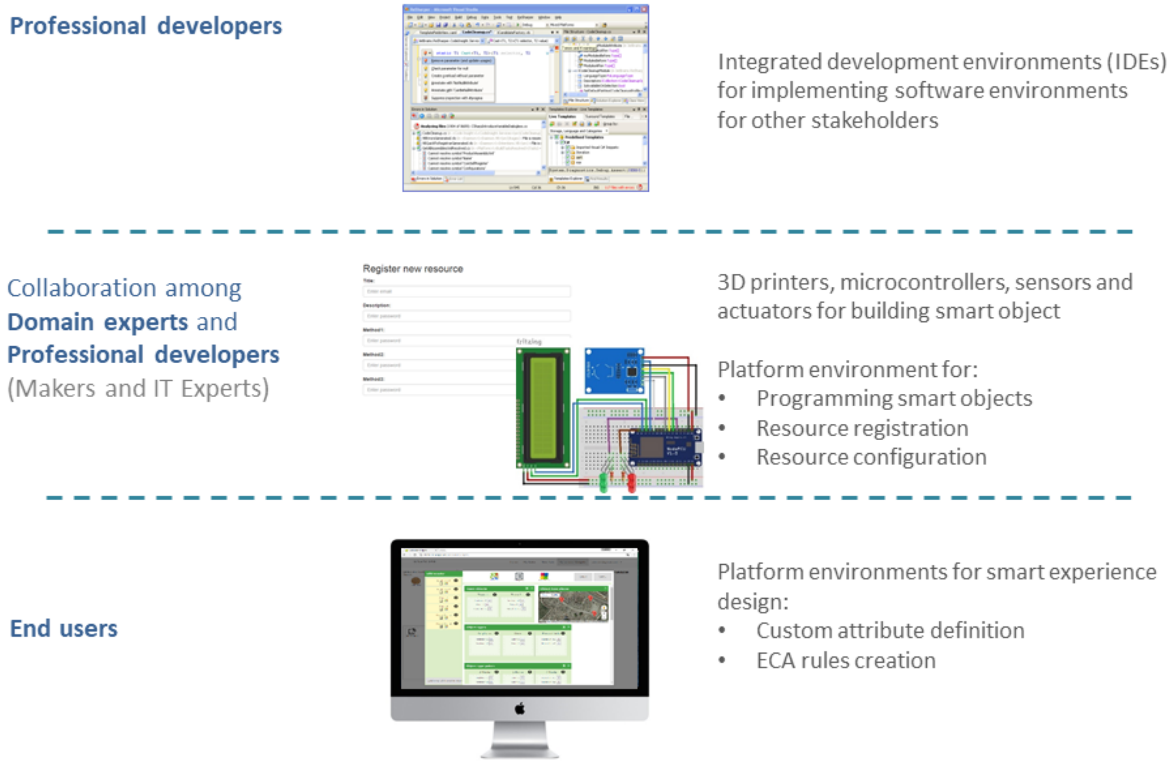

Figure 3. The three-layer meta-design model adopted in EFESTO-SE to support the creation of smart experiences.

In the Rocco's scenario, the main resources of the smart experiences are the guide's device, the team's RFID cards and the Game Engine Web service. Such resources are developed respectively by makers and IT experts, who know how to program them. Rocco, acting as domain expert, collaborates with them to configure such resources in EFESTO-SE, by selecting those elements of the smart objects (i.e., events and actions) that actually make sense in the smart experience he wants to define. After the customization of EFESTO-SE, as represented at the *bottom-layer* of Figure 3, the creation of the smart experience is a mix of use and design activities. The end user (e.g., Rocco in our scenario or any other guide who wants to create a similar visit experience) *uses* the customized platform to *design* the smart experiences to be proposed to the final visitors. In the customized visual design environment, Rocco gets a visual representation of the defined elements, i.e., the smart objects, the Web services, and all their events, actions, and custom attributes. He will be able to use them to define rules governing the smart experience. The design generates a running application governing the smart visit, which can be still modified by acting visually on the designed rules.

It is worth noting that the whole methodology is based on an iterative process. Whenever the resources available in the platform do not satisfy the requirements of the smart experience under design, the end users can refer to the stakeholders at the upper layers. For example, during the development of his smart experience, Rocco might need to introduce a new functionality in the guide's device, such as the possibility to emit sounds when an RFID card is read. Thus, he communicates this new need to the stakeholders at the upper layer. The maker adds a speaker inside the Guide's and the IT experts register and configure such a new actuator in the platform. From that moment on, Rocco can use the speaker when defining ECA rules.

In the following, we describe in detail how the makers build the guide's device and the other smart objects (Section 5.2), how the IT experts develop the Game Engine (Section 5.3), and how these resources are registered and configured in EFESTO-SE (Section 5.4). Afterwards, we illustrate how Rocco use EFESTO-SE to build the interactive experience by creating custom attributes and ECA rules (Section 5.5).

5.2. Building the Smart Objects

The guide's device is a Mouth of Truth (MoT), i.e., a smart object with the capability to connect to the Internet, read smart cards (user input), show messages on a display and blink its eyes. Since such an object does not exist yet and Rocco is not an ICT expert, he goes to a makerspace in his city, where a maker builds the MoT device shown in Figure 4.

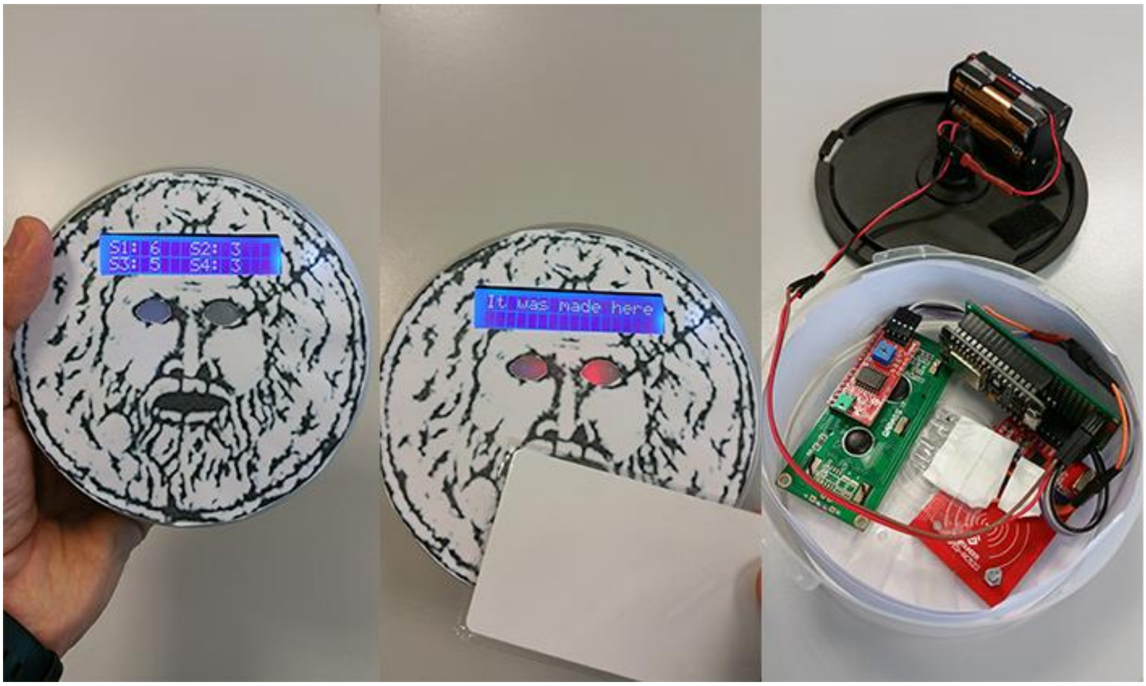

Figure 4. The Mouth of Truth smart object built to develop the scenario "game in the archaeological park".

The MoT appears as a cylindrical container with a print of the Mouth of Truth Roman monument on top (left image of Figure 4). Inside the container (right image of Figure 4), as represented in the MoT circuit schema in Figure 5, a nodeMCU microcontroller board is connected to sensors and actuators and determines the MoT functionality [NodeMcu Team 2017]. An RC-522 RFID reader, positioned under the MoT mouth, detects the RFID cards used by visitors (middle image of Figure 4). Two red and two green RGB LEDs, placed in the MoT eye sockets, blink according to card used. An LCD display, positioned at the forehead of the mask, shows messages to the users, e.g., the game score. The leftmost image of Figure 4 shows the game score of four teams participating to the game. An ESP8266 Wi-Fi module integrated in the nodeMCU board allows the MoT to communicate wirelessly and to connect to the Internet. Depending on the site infrastructure, the MoT can be connected through a router in the park or through a local network managed by the guide's mobile device. Other possibilities, such as 3G/4G connections, are also feasible but the MoT should be equipped with a 3G/4G module, which requires more battery power. Furthermore, in case of multiple MoTs, a contract with an Internet provider for each device is required, while using the Wi-Fi module the guide's mobile device connection can be shared with several MoTs. The GPS position is acquired through the guide's mobile device: a MoT GPS antenna would need too much time to get GPS data and the antenna must be always on, thus consuming the battery quickly.

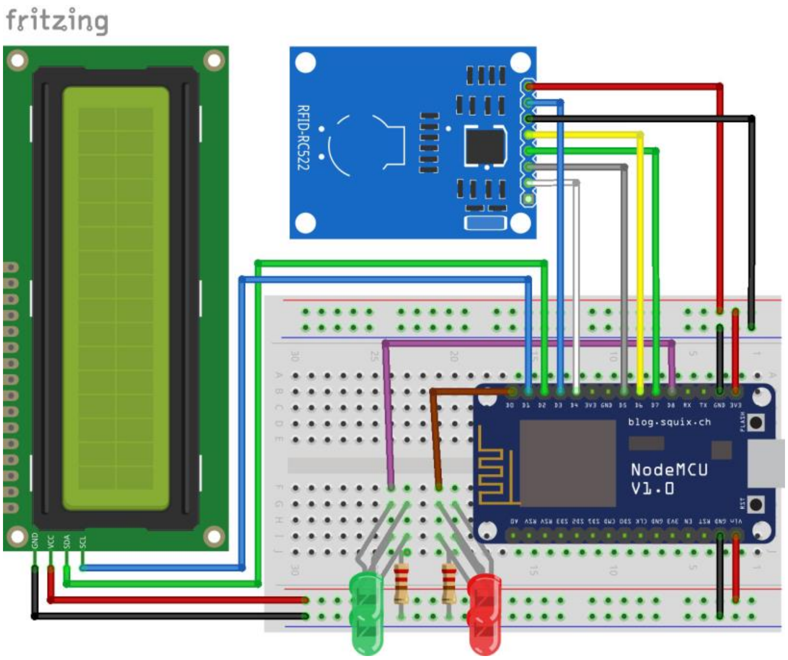

Figure 5. Electric schema of the Mouth of the Truth used by the guide.

Afterwards, the maker prints the pictures related to sensible locations of Egnathia provided by Rocco, and attaches them on cards provided with an RFID tag. In order to make the functionality of the device remotely accessible, for example to remotely read the data produced by the sensors and send commands to the actuators, the maker publishes some dedicated software services through a cloud provider. In the case of Rocco's MoT, the maker creates and publishes services for accessing some sensed data (e.g., the GPS position) and actuating some actions (e.g., switching on/off the MoT LEDs).

5.3. Programming the Game Engine Web service

The Rocco's smart game also requires managing the assignment of points to teams. To this aim, Rocco asks an IT expert to develop a solution that satisfies this requirement. Thus, the IT expert builds a Web service that exposes operations for assigning points to a specific team (*AssignPointToTeam(Points,targetTeam)*), for retrieving the current number of points of a team (*PointsGained(targetTeam)*), and for retrieving the team with the highest score (*WinningScoreReached*(*targetTeam)*). Moreover, such Web service is registered on the server of a cloud provider, so that it is remotely accessible.

In our prototype, such services have been developed by using Node-RED. Node-RED is a platform for wiring together different components (i.e., APIs, online services, hardware devices); it offers a visual, graph-based, notation. The services are deployed on an IBM Blue Mix account and can be invoked through the RESTful protocol, which guarantees an easy access to online resources and is supported by many platforms, thus favoring service interoperability.

5.4. Registering smart objects and services in EFESTO-SE

Some works in the literature show that the end users of composition platforms generally encounter problems when they are exposed to a high number of different, non-pertinent options [Desolda et al. 2017a; Ghiani et al. 2017]. In our case, the smart-experience resources built by the professional developers can have an internal complexity that goes beyond the needs of the specific usage scenarios to be addressed, or that do not necessarily have to be made evident to non-technical smart-experience designers. According to the middle layer of our meta-design model, during a customization phase professional developers and domain experts collaborate to wrap and register the original resources so that only the elements significant for the scenario are made available into the design environment.

In the Rocco's scenario, the platform customization mainly consists in registering and configuring the events and actions for the MoT device, the RFID cards, and the Game Engine Web service. Professional developers use an administration panel available in EFESTO-SE to indicate all the information needed to access to events and actions. For example, the professional developer specifies the list of service methods, their base URI, their type (e.g., GET, POST), their authentication type (e.g., OAuth or OAuth 2.0). Such details, stored in a JSON descriptor, are used at runtime to invoke the services. Other data to be specified are the name and description of the events and actions that the service methods are supposed to manage. Such additional data are also stored in the JSON descriptor and are used at design time for the visualization of available events and actions in the visual environment dedicated to the creation of rules.

5.5. Using EFESTO-SE to design the Smart Experience

The EFESTO-SE prototype is a Web application[**] that offers a rich design environment enabling the visual composition of smart experiences through the modeling constructs illustrated in Section 4. It

** EFESTO-SE implementation uses the Java Spring framework. Its user interface (UI) was programmed by using Thymeleaf, a Java HTML5 template engine, and the Bootstrap front-end framework. The use of Bootstrap allowed us to build responsive UIs, which adapt their layout to the device on which they are run (e.g. PCs, smartphone, tablet). All the prototypes have been deployed on a virtual machine created in the Windows Azure cloud platform (4 core, 8Gb RAM, Windows Server 2012).

implements two main sections related to the most characterizing aspects of the approach and the model, i.e., the one to define smart-object custom attributes (see Section 5.5.1) and the one to create ECA rules (see Section 5.5.2. In the following, EFESTO-SE usage is illustrated by describing how Rocco would create the serious game to be played at the archaeological park.

5.5.1. Defining custom attributes

EFESTO-SE offers a paradigm for visual design that is grounded on the Transformative User Experience (TUX) principles [Latzina and Beringer 2012]. Such principles were already implemented in a mashup platform [Ardito et al. 2015b]; their basic idea is to manipulate data extracted from different data sources inside *visual containers* that give to data different semantics, i.e., new visualizations and/or functions actionable on them. In line with this previous approach, in EFESTO-SE we introduce *Visual Annotation Containers* (VACs), i.e., graphical widgets devoted to the definition of custom attributes on smart objects. The idea is that the users add the VAC widget to the visual design environment and customize its name and content to define a new custom attribute. Each VAC has an intrinsic semantics, i.e., it can be used to define custom attributes with a given role (for example, representing locations). In our current version of EFESTO-SE we developed three types of VAC, i.e., *Location*, *Categories* and *Association*. The Location VAC is a widget that allows designers to position some objects on a map to associate them with some coordinates (point values or ranges of coordinates). The designer can then give a name to the selected location (e.g., “discovery place”) to express the meaning of the coordinates reached during the visit. The container *Categories* allows the designer to specify attributes that correspond to categories of smart objects. It enables the definition of categorical terms and the definition of groups of resources related to these terms. The *Associations* container enables the definition of properties that can hold different values for different resources. The VAC in this case represents a property; through two different columns, the designer can then specify pairs whose first element represents a value assumed by the property and the second element represents the resource that holds this value.

Figure 6 shows the platform workspace where Rocco defines some custom attributes for the resources previously configured with the help of professional developers. The list of smart objects is shown in the left-side bar. Rocco has already added 6 RFID cards and given them a name (e.g., Amphora n.1, Coin n.1, etc.). Through the VACs shown in the right-hand area of the workspace, he then defines the custom attributes. In particular, Rocco adds into the design space two “Categories” VACs to define some categorical terms for some smart objects. Rocco names one VAC *Team*, he adds two columns (Team 1 and Team 2) and drags in them the RFID cards to be associated to Team 1 or Team 2, respectively. As a result, those cards are annotated with the “Team” category attribute and the corresponding values Team 1 or Team 2. This attribute is important for identifying which teams will be using the RFID cards during the game. Rocco does the same for assigning, to every RFID card, the *HistoricalAge* custom attribute – with values “Roman” and “Messapian”. Afterwards, Rocco adds the association VAC named *Points* to define the score value that each card allows to gain during the game (e.g., 5, 7, 22). The *Location* container finally allows the designer to position a smart object on a map, to assign it with the GPS coordinates of relevant locations to be monitored during the game. A meaningful name can also be defined for the selected location, and it will be then available as parameter for the definition of rule conditions. Indeed, every custom attribute defined visually is also stored in the JSON descriptor of the smart object, so that successively such properties can be retrieved and visualized in the visual environment where ECA rules can be defined.

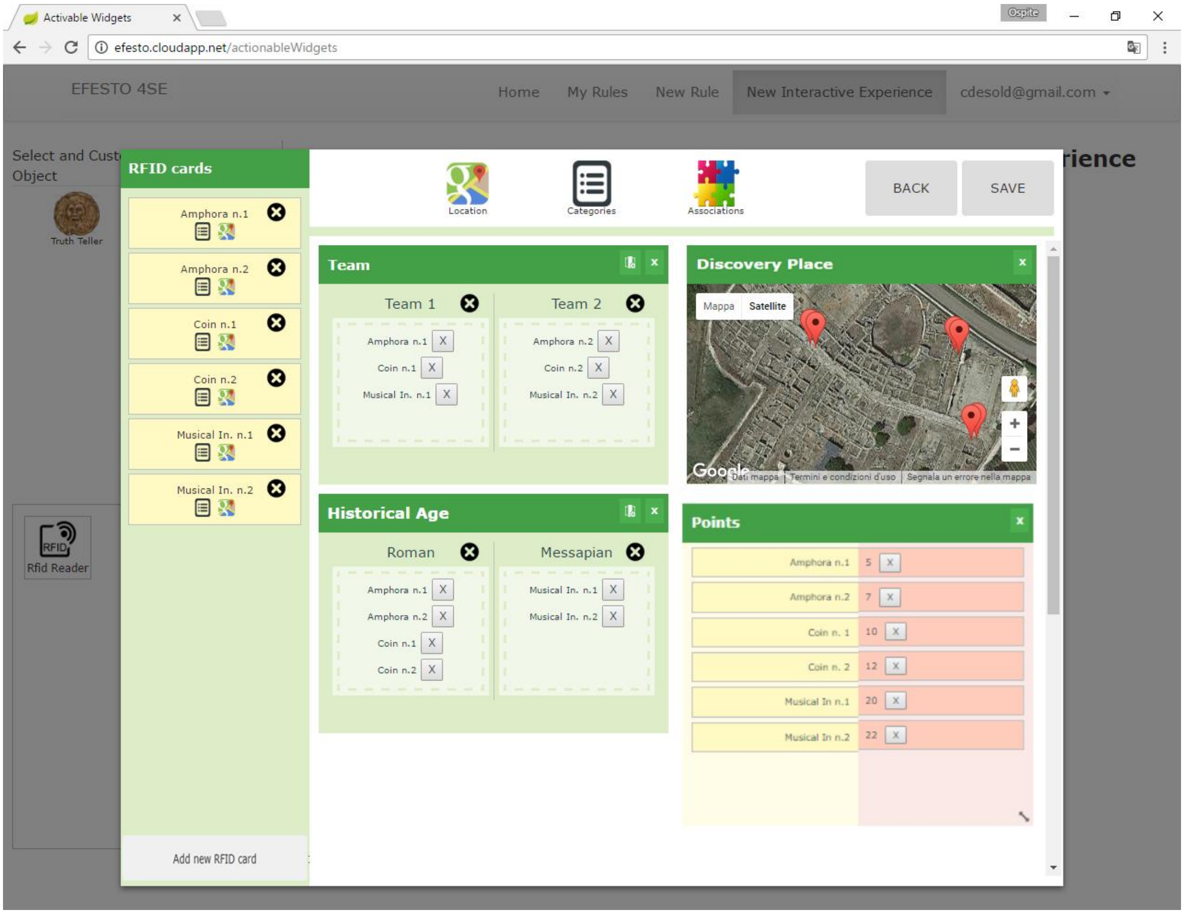

Figure 6. Defining objects and their attributes for the scenario “game in the archaeological park”.

5.5.2. Defining rules for synchronizing resources

After defining the custom attributes, Rocco defines the rules that will govern the synchronization of the different resources during the interactive game. As illustrated in the previous sections, resource synchronizations is technically managed through Event-Condition-Actions (ECA) rules [Pane et al. 2001]. To support users without computer-programming skills to define ECA rules, our visual design approach proposes a composition paradigm that does not follows exactly the ECA rule syntax [Desolda et al. 2017a]. The design of such paradigm is the result of a study where participants proposed ideas for novel user interfaces for ECA rule definition [Desolda et al. 2017a]. One evident difference between an ECA rule and its visual definition in EFESTO-SE is that the rule is composed of two parts: *i)* a *conditioned events* part, i.e., a logical concatenation of triggering conditions that focus on both the occurrence of events and on conditions over event parameters; *ii)* the *action* part, i.e., a logical concatenation of actions that can be activated only if all the conditions in the previous part of the rule are satisfied. In other words, the condition part is fused with the event part. This because non-programmers do not perceive the difference between specifying the occurrence of events and expressing conditions over event parameters [Desolda et al. 2017c]. Both are conceived as events that must occur in order for the rule to be activated. This visual syntax is indeed adopted by different tools for task automation that especially address non-technical users [Coronado and Iglesias 2016; Crafty Apps 2017; IFTTT Inc. 2017; Itrios LLC 2017; SmarterApps Ltd 2016; WigWag Inc. 2017].

Going back to our reference example, in the visual environment for rule specification, Rocco sees also the list of custom attributes that he previously defined for the smart objects; he is thus enabled to use them 1) as variables within conditions constraining the rule activation and 2) as parameters in the rule events/actions. Let us suppose that Rocco would like to create an ECA rule that, formally, is defined as follows:

ru = E_{ru} = < *MoT.RFIDCardRead* >
C_{ru} = < (*MoT.Modality* is equal to *LocationMatching*) AND (*MoT.SensiblePosition* is equal to *RFIDCard.DiscoveryPlace*)>
A_{ru} = <(*MoT.BlinkEyes(Green, NSeconds*) AND *(GameEngine.AssignPointToTeam(RFIDcard.Points, RFIDcard.Team))* >

The condition "*MoT.SensiblePosition* is equal to *RFIDCard.DiscoveryPlace*" is true if the MoT GPS position reached during the visit is equal to the value of the *DiscoveryPlace* attribute specified for the RFID card read by the MoT. The action invokes a Game Engine operation that assigns the points associated to the read RFID card to the team of the card itself.

In order to define the previous rule in EFESTO-SE, Rocco enters the rule-creation area. Then he clicks the "+Event" button (Figure 7, circle 1) and a wizard procedure allows him to selects the *MoT* object and the *RFID CardRead* event. The wizard retrieves the name of the available events from the descriptor files created when the smart-object services are registered into the platform. Thus, Rocco creates the first rule event (Figure 7, circle 2). To define the condition that triggers the rule, he clicks again the "+Event", selects the *MoT* object and the *Sensible Position* event, and specifies as parameter the *Discovery Place* of the read RFID card (Figure 7, circle 3).

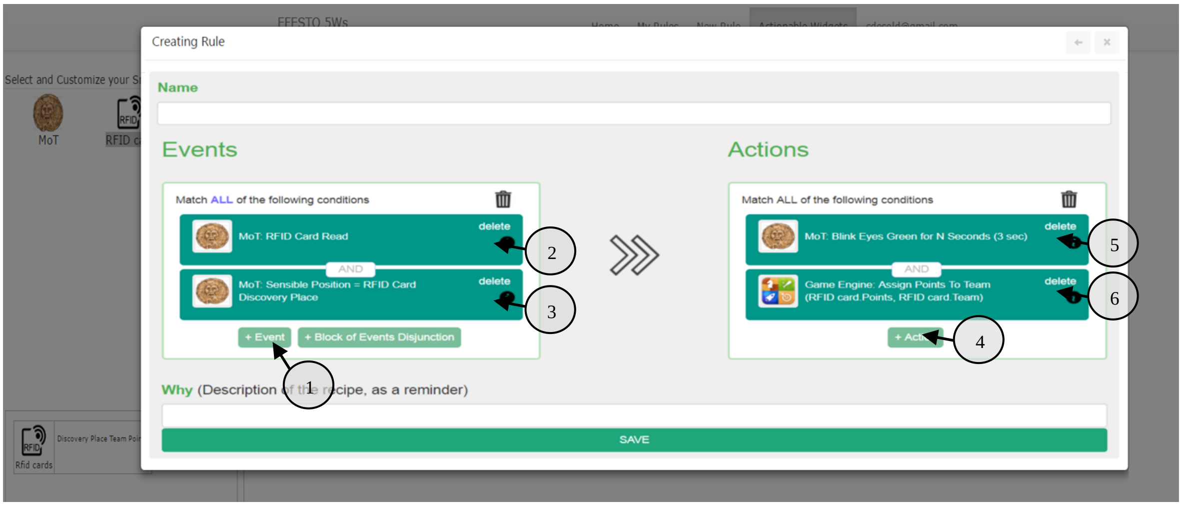

Figure 7. Example of ECA rule created for the scenario "game in the archaeological park".

After defining the events, Rocco create the actions to be executed when the event conditions are satisfied. Rocco clicks on the "+ Action" button (Figure 7, circle 4) and chooses the *Mouth of Truth*, selects the *Blink Eyes Green for N Second* action and specifies, as action parameter, the number of seconds the LED have to blink (Figure 7, circle 5). Afterwards, he adds a second action (Figure 7, circle 6) by selecting the service *Game Engine* and its *Assign Point To Team* action, and specifying as action parameters the number of points (*RFID card Points* attribute) and the team (*RFID card Team* attribute). Once saved, the rule is immediately active and the objects involved in the rule behave accordingly. In other words, the game is ready to be played.

6. Evaluation with CH Guides

An evaluation of the EFESTO-SE running prototype was performed through a study inspired by [Hamilton and Wigdor 2014], called utilization study since participants are required to perform real tasks using the prototype. In particular, we involved 14 professional cultural-heritage guides who were asked to use EFESTO-SE to create an interactive experience according to a given scenario. In this study the goal was the assessment of the usability of the composition paradigm implemented in EFESTO-SE in respect to the CH guides' mental model.

6.1. Participants

We recruited 14 participants (5 female) aged between 18 and 50 ($\bar{x} = 37.9$, $SD = 8.2$). Specifically, 3 out of the 4 professional guides of the WWF wildlife park of Torre Guaceto (Italy) who were involved in the elicitation study; 1 professional guide operating in different Natural Science museums in Italy; 8 professional guides of an association that organizes guided tours in natural and archaeological sites of the Basilicata region in Southern Italy; two professional guides of archaeological sites in various regions Southern Italy.

6.2. Procedure

The study took place in quiet and isolated settings, where we installed the study apparatus (a laptop connected to an external monitor and a web camera, see Figure 8). Two Human-Computer Interaction researchers were involved in the study: one (facilitator) was in charge of introducing users to the study and following them during the tasks accomplishment; the second one (observer) took notes.

The guides participated individually and underwent the same procedure, which lasted about 1 hour. First, the participant was asked to sign a consent form. Then, the facilitator showed a quick introduction about the use of EFESTO-SE and assisted the participant while performing three training tasks with it. The participant was required to design a smart visit experience in accordance to a scenario that was very similar to the game designed by the archaeological park guide in the elicitation study (see Section 3.5). Summarizing the scenario, visitors are divided in two teams, each provided with a deck of smart cards, while Rocco, i.e., the guide, has a Mouth of Truth (MoT) device. At specific points of interest, Rocco asks questions and each team provides the answer by inserting a proper smart card into the MoT device, which reads the card and provides a feedback about the answer correctness, giving a score if the answer is correct.

In the test session, in order to create the smart visit experience, the participant was provided with a sheet reporting the scenario and the tasks to be performed by using the EFESTO-SE platform. The tasks were:

- Assign to each object, namely to the MoT device and to the team's cards, the custom attributes that you think better characterize their semantics in the scenario;
- Create the rules that define the behavior of the smart objects in the desired smart experience.

It is worth mentioning that the participant was also provided with the smart objects addressed in the scenario, namely the MoT device and two decks of cards, each deck consisting of the same five cards. Indeed, we wanted to give the participant the possibility to see and touch these objects, in order to stimulate their creativity.

During the interaction with the platform prototype, the participant was asked to verbalize his/her thoughts and comments according to the think-aloud protocol. At the end, the participant filled out the online questionnaire and participated to a de-briefing phase to clarify some of the externalized comments and to provide further feedbacks.

The scenario was slightly adapted to the guides' specificity. For example, in the case of the WWF guides, Rocco was a guide of the wildlife park and the smart cards reproduced flora and fauna pictures of the Torre Guaceto oasis.

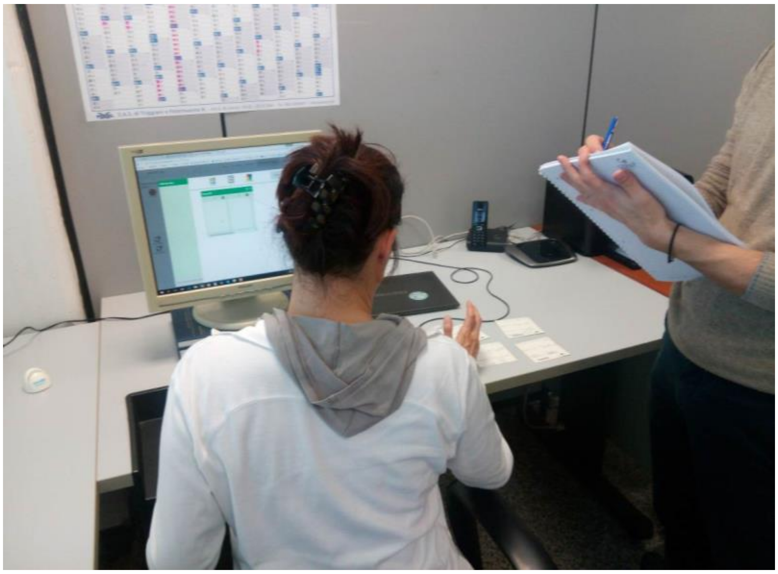

Figure 8. A participant and the facilitator during the evaluation study.

6.3. Collected data

During the utilization study, we collected different qualitative data. All the interactions were audio-video recorded by using an external camera. Notes were taken by the observers on significant behavior or externalized comments and during the de-briefing phase. The collected notes were extended by video-analysis, as for the previous elicitation study. The videos were independently transcribed by each of the two researchers involved in the study, literally noting down all intelligible speech. Then, together they analyzed the transcripts and found out an initial agreement value of 74%. The remaining 26% of discrepancies were solved by discussion. The transcribed data were annotated by using different colored markers to categorize the content under emerging themes. Then all the data were grouped, through the affinity diagram technique proposed in [Rogers et al. 2015], under main themes related to usability issues, as well as advantages and disadvantages of using the proposed solutions.

To evaluate user satisfaction, a questionnaire with 23 statements was administered at the end of the study. The first statement was the Net Promoter Score (NPS) question [Grisaffe 2007], typically used to measures, on a scale between 0 and 10, how likely users would recommend the product to a friend or a colleague. The resulting score is an absolute number lying between -100 and +100 calculated as the difference between the percentage of promoters (users who scored the system >= 9) and detractors (users who scored the system <= 6). In general, a positive score is considered good while a score over 50 is excellent. We included it in the administered questionnaire to obtain a single value as summary of the overall users' satisfaction. The next 10 questions were the ones of the SUS (System Usability Scale) questionnaire [Brooke 1996], which is highly reliable [Bangor et al. 2008], technology agnostic and effective also for evaluating usability of modern technology [Brooke 2013]. We introduced the SUS statements to obtain more details about the EFESTO-SE usability and learnability. The last 12 questions were then introduced to deeply evaluate the main features of EFESTO-SE, namely 1) the creation of the custom attributes and 2) the definition of ECA rules. To this aim, we used the NASA-TLX questionnaire by formulating its 6 statements (Mental demand, Physical Demand, Temporal Demand, Performance, Effort, Frustration; all subscales range from 0 = low to 10 = high) for each of these two EFESTO-SE features [Hart and Staveland 1988].

6.4. Results

Important indications come from the questionnaire. The first one was obtained by the NPS score that is equal to 57, i.e., excellent. It appears promising because it indicates an attitude towards suggesting this system to other CH guides. The encouraging NPS result is confirmed by the analysis of the SUS questions, which gave us detailed indications about the perceived system usability and learnability. The SUS global score was 81.1/100 (SD = 14.1), which is higher than the average SUS scores (69.5) of one thousand studies reported in [Bangor et al. 2009]. According to the SUS adjective rating scales [Bangor et al. 2009], this score can be considered an excellent result. In addition, according to [Lewis and Sauro 2009], we split the overall SUS score into two factors, i.e., System Learnability (considering statements #4 and #10) and System Usability (all the other statements). The *System Learnability* score was 75.9 (SD = 22.2), while the *System Usability* score was 82.4 (SD = 12.8). Thanks to the analysis of the notes and video recordings, as well as the NASA-TLX results, we can attribute the lower learnability score mainly to the difficulties that participants experienced with the creation of custom attributes.

To investigate the usability of EFESTO-SE with respect to its two main features, i.e., *attributes creation* and *rules definition*, we analyzed the results of the NASA-TLX statements. Figure 9 depicts, for each feature, all the NASA-TLX dimensions' scores. Regarding the *Frustration*, both the features obtained a low score (attribute creation = 2.79/10, rule definition = 2.64/10), indicating that participants did not feel frustrated while creating CAs or ECA rules. Regarding the *Effort*, both the features obtained a medium score (attribute creation = 4.07/10, rule definition = 3.07/10) suggesting that participants had to put some effort in performing the tasks' scenario. Looking to the *Mental Demand* and *Physical Demand*, we can attribute the previous score, i.e., Effort, to a medium mental effort (attribute creation = 3.93/10, rule definition = 3.5/10), while physical effort was quite low (attribute creation = 1.57/10, rule definition = 1.93/10). The *Performance* obtained a positive value in both the dimensions (attribute creation = 7.43/10, rule definition = 6.79/10), indicating a good satisfaction in using the system. Lastly, the *Temporal Demand* dimension revealed that participants did not feel to need a long time to create attributes and define rules (attribute creation = 3.29/10, rule definition = 2.86/10).

The thematic analysis carried out on the transcribed data, triangulated with the questionnaire results, allowed us to identify important themes highlighting the presence of some usability issues to be addressed, as discussed in the next subsection.

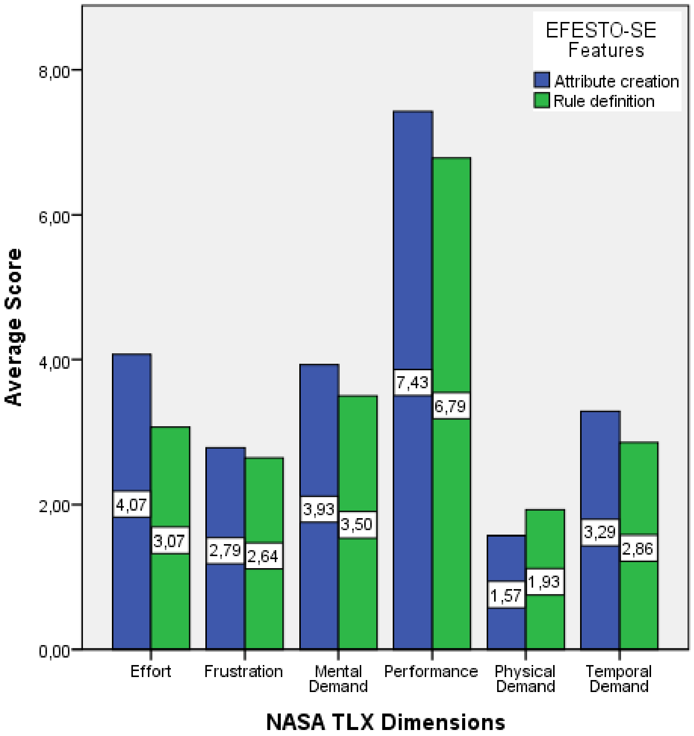

Figure 9. NASA-TLX dimensions related to the custom attributes definition and ECA rule creation.

6.5. Discussion

This section discusses the main themes that emerged from the study results and reports the derived design implications.

Constraining the flow of design activities. EFESTO-SE supports the creation of smart experiences by asking users to take part to different phases: the initial configuration of smart objects, the creation of custom attributes (CAs) and their association with smart objects, and the definition of ECA rules determining cross-object interactions. One problem observed during the study regards the management of all these phases: two participants, indeed, reported that EFESTO-SE should be more effective in guiding users in the overall process. Actually, the definition of CAs and ECA rules occurs into two separated windows and this distinction confused the participants, who had to switch among them during the smart-experience design. Users suggested to make clear: 1) the order of the steps to create the smart experience, i.e., first “CA creation” and then the “ECA rules definition”; 2) the current status of the smart experience under creation, in terms of already defined smart objects, CA and ECA rules. Based on the observed problems and participants' suggestions, we believe that our environment for the creation smart experiences should be redesigned to provide a robust guidance to users. For example, a wizard procedure can guide users in configuring an initial, limited core set of smart objects, together with their CAs and basic ECA rules controlling them. Later, users can freely continue expanding this core set until obtaining the final and complete smart experience. This is in line with some findings that we already achieved in previous studies related to the paradigm for ECA rule creation [Desolda et al. 2017a]. In a comparison of three different interaction paradigms, a wizard-based procedure, which guides the users along a sequence of design steps, emerged as the most promising one.

Simplifying the paradigm for CA definition. As explained in Section 3, the interaction paradigm that we implemented for the creation of CAs is based on TUX principles [Beringer and Latzina 2015] and the notion of visual containers that we already adopted in our previous work [Ardito et al. 2015b]. As emerged by triangulating questionnaire results with users' comments, CA definition resulted more difficult than ECA rules creation. The low SUS learnability score reveals that the users encountered some difficulties in learning EFESTO-SE. The NASA-TLX scores then helped us identify that the CA definition phase (for which the *Effort* and *Mental demand* were higher) is responsible for the low SUS learnability score. The NASA-TLX results were also confirmed by the analysis of the externalized comments. For example, 6 participants did not understand autonomously how to create the annotation containers, and asked facilitators for help. No significant problems were instead observed when the participants created ECA rules.

It is worth mentioning that the ECA rule paradigm is more mature than the one for CA definition, thanks to the previous studies performed to elicit and evaluate it [Desolda et al. 2017a]. However, these results suggest us that the TUX paradigm can be effective when the containers represent transformations for data elements moved within them, as it was in our previous version of the composition platform. It could be instead perceived as less intuitive when the movement across containers is meant to *extend* the moved objects with new properties rather than *transform* objects by means of functions operating on them. In this case, indeed, other metaphors for the property assignment could be perceived as more usable. For example, one participant suggested a spreadsheet-based solution: users could use a tabular format in which they allocate smart objects in rows, CA names in columns, and then specify CA values in cells located at the intersection between rows and columns. The tabular format was also adopted in the elicitation study by the CH guides to specify CAs and their values.

Stimulating creativity in smart-experience design. Another important aspect in CA definition and, more in general, to smart-experience design, is the adoption of paradigms that can stimulate creativity. The evaluation study demonstrated that EFESTO-SE is a promising support in the design of smart experiences. However, discussions with participants revealed that there is still room for improvements. For example, three participants during the de-briefing phase proposed the adoption of more natural interaction paradigms as a means to stimulate creativity, especially when defining CAs. In particular, one participant envisioned a solution where the proximity to objects or locations of the physical environment can be used to inherit semantics properties to be assigned to smart objects. In general, given the nature of smart objects as devices the users can physically interact with, we agree that novel tangible mechanisms for custom attribute definition have to be adopted to take into account the physicality of the interaction and the possibility to explore naturally properties of the physical environment.

Supporting and fostering technical skills growth. Another aspect emerged during the discussion with the CH experts regards the customization activities that go beyond the smart object programming supported by EFESTO-SE. Indeed, 6 out of 14 participants stated that, after a certain period of EFESTO-SE usage, they would like to be supported in extending the smart object capabilities by integrating new sensors and actuators, avoiding to involve every time IT experts. Even if this activity seems an aspect that only technicians can accomplish, today there are hardware and software solutions that satisfy this goal. For example, *mCookies*[††] is an alternative to Arduino that can support people who have an interest in electronic "Do It Yourself". It consists in a set of magnetic, color-coded modules, which can be staked in a LEGO fashion. People can combine sensors and actuators without soldering anything but by simply staking the needed sensors/actuators

†† http://microduinoinc.com/products/mcookie/

modules. In the Rocco's scenario, in case he needs to add a speaker to the MoT to emit sounds when a card is read, he would just need to stack the speaker module and program the MoT behaviour in EFESTO-SE. A different approach is provided by visual tools like *circuito.io*‡‡ that provide interfaces to combine, by means of drag&drop actions, different boards, sensors, actuators, producing at the end all the instructions to wire the real components, as well as the programming code to be uploaded on the board. These kinds of solutions should be took into account when developing smart objects and integrated into the systems to program them, in order to ensure people who are interested in more complex customization operation a "gentle slope of difficulty" [Lieberman et al. 2006a].

7. Conclusion

This article has presented our perspective on the EUD of smart visit experiences. We showed how we extended and customized a generic composition paradigm, initially conceived for the EUD of IoT systems, to respond to the need of exploiting IoT to mediate narrative and content-appropriation goals for interactive visits to CH sites. We started from a composition paradigm for ECA rule specification whose capability to support non-programmers was already assessed through a number of studies [Desolda et al. 2017a]. We also considered some principles for the design of systems that facilitate users to manipulate flexibly information, and to make sense of it with respect to situational needs [Latzina and Beringer 2012]. We then identified and validated, with the help of professional CH guides, some hypotheses on how to transpose such principles to the flexible definition of smart visit experiences. The goal was to support the composition of smart objects that need to be put in context with respect to CH site scenarios where they are used by visitors. A first study conducted with guides of CH sites showed that our hypotheses on extending the semantics of smart objects by means of custom attributes were valid with respect to the expectations of CH stakeholders. We thus implemented the resulting composition paradigm into the EFESTO-SE running prototype, which was evaluated with CH guides.

The work described here provides the first results of a larger research that aims to promote smart objects as components of a smart experience that can bring with themselves evident connections with the semantics of content for which they facilitate the access. This gives to smart objects a new flavor, not only as technical devices able to sense and control the environment, but also as components that can be seamlessly integrated with the surrounding content, as they bring with themselves properties that facilitate the specification of goals for content appropriation. As such, they can better stimulate the creativity of CH stakeholder as smart-experience designers: if the smart objects make evident the relationship they have with the content, CH professionals can better identify how to adopt such devices to convey the CH-site content to visitors. We are further exploring and verifying this aspect in some recently undertaken research activities, which are devoted to compare different composition paradigms, not only visual but also based on natural interaction, to verify in which measure they can support the exploration of the surrounding environment as a source of custom attributes for annotating smart objects [Ardito et al. 2017].

We want to remark that in our approach extending the semantics of smart objects does not simply mean representing some knowledge in the system. Our approach indeed focuses on stimulating end users to define by themselves and represent in the system such semantics. Nevertheless, this perspective and the enabling composition paradigm can be complemented with methods for knowledge representation, for example based on ontologies, so that the end users can also be supported in the identification of sensible properties. This is

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‡‡ https://www.circuito.io/

one of the possible extensions that will be investigated in our future work. Another possibility to enhance the definition of smart-object semantic can be to exploit collaborative, community-based paradigms, where different domain experts can collaborate and share ideas on how to characterize smart objects for CH sites. Other improvements can be related to extending the paradigm for rule definition to capture better the complexity of some smart-experience scenarios. For example, some situations could require the possibility to define an order in the activation of rules, for example by means of phases of the smart experience that can be entered only if some pre-conditions are satisfied or some goals are reached by the participants. Some other situations could require the randomness of the actions to be actuated over the environment. These aspects can be relevant when IoT has to support articulated and engaging visit experiences to CH sites; but there are also other domains where these needs become evident. One is for example e-health, where smart objects are exploited in therapy scenarios characterized by both incremental learning goals and situations where random stimuli can be exploited to engage the patients [Garzotto et al. 2016]. Indeed, even if in this article we specifically focus on CH scenarios and smart visit experiences, we believe that our approach, properly extended, can be adopted in any other domain where non-technical stakeholders need to configure engaging smart experiences.

As far as the usability of the composition paradigm is concerned, we are planning to conduct comparative studies to understand whether different composition metaphors (e.g., those based on wizard procedures) would be more effective. One of the problems that emerged in the evaluation study was related to the lack of support in the definition of the control flow when creating the smart experience. Our previous studies on ECA rules composition highlighted that wizard-based paradigms are very effective in guiding users through different steps and also outperformed other paradigms in terms of users' performance and satisfaction. We expect that a wizard-based approach would also be beneficial for the definition of custom attributes and for the specification of a flow among different rules according to progressive goals to be reached. Progressive activation of rules also requires the expression of temporal constraints. This is an aspect that we did not investigated so far and that will be the object of our future work. We however want to stress that, independently of the visual metaphor adopted in the platform prototype, which we are going to evaluate and improve through future studies, the main contribution of this article is the set of abstractions that we identified for the composition of smart experiences by non-technical end users.

Finally, we want to remark that in this article we put emphasis on the composition of smart experiences, while we purposely did not validate the effectiveness of the resulting smart experience with respect to the final participants. We however already planned some field studies to assess the validity of our solution also with respect to the effectiveness of the resulting smart experience.

Acknowledgments

This work is partially funded by the Italian project SHELL (Shared Interoperable Home Ecosystems for a Green, ComfortabLe and Safe Living - CTN01 00128 111357) and by the project COSMOS (Creation Of SMart spaces fOr end-uSer empowerment) funded by the University of Bari Aldo Moro. We are immensely grateful to Prof. Maria Francesca Costabile for her valuable and constant support. We also thank the professional CH guides who enjoyed reasoning with us on sensible scenarios and requirements, and those ones who participated to the study for evaluating the visual paradigm for custom attribute definition.

References

Angelaccio, M., Basili, A., Buttarazzi, B. and Liguori, W. (2012). Smart and Mobile Access to Cultural Heritage Resources: A Case Study on Ancient Italian Renaissance Villas. In *Proc. of the Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE '12)*. IEEE Computer Society, Washington, DC, USA, 310-314.

Antoniou, A. and Lepouras, G. (2010). Modeling visitors' profiles: A study to investigate adaptation aspects for museum learning technologies. *Journal on Computing and Cultural Heritage*, 3(2), 1-19.

Ardito, C., Bottoni, P., Costabile, M.F., Desolda, G., Matera, M. and Picozzi, M. (2014a). Creation and Use of Service-based Distributed Interactive Workspaces. *Journal of Visual Languages & Computing*, 25(6), 717-726.

Ardito, C., Buono, P., Costabile, M.F. and Desolda, G. (2015a). Interaction with large displays: a survey. *ACM Computing Survey*, 47(3), 1-38.

Ardito, C., Buono, P., Costabile, M.F., Lanzilotti, R. and Piccinno, A. (2012a). End users as co-designers of their own tools and products. *Journal of Visual Languages & Computing*, 23(2), 78-90.

Ardito, C., Costabile, M.F., De Angeli, A. and Lanzilotti, R. (2012b). Enriching archaeological parks with contextual sounds and mobile technology. *ACM Transactions on Computer-Human Interaction*, 19(4), Article 29 (December 2012), 29 pages.

Ardito, C., Costabile, M.F., De Angeli, A. and Lanzilotti, R. (2012c). Enriching exploration of archaeological parks with mobile technology. *ACM Transaction on Computer-Human Interaction*, 19(4), Article 29 (Decemer 2012), 31 pages.

Ardito, C., Costabile, M.F., De Angeli, A. and Pittarello, F. (2007). Navigation help in 3D worlds: some empirical evidences on use of sound. *Multimedia Tools and Applications*, 33(2), 201-216.

Ardito, C., Costabile, M.F., Desolda, G., Lanzilotti, R., Matera, M., Piccinno, A. and Picozzi, M. (2014b). User-Driven Visual Composition of Service-Based Interactive Spaces. *Journal of Visual Languages & Computing*, 25(4), 278-296.

Ardito, C., Costabile, M.F., Desolda, G., Latzina, M. and Matera, M. (2015b). Making Mashups Actionable Through Elastic Design Principles. In: P. Díaz, V. Pipek, C. Ardito, C. Jensen, I. Aedo and A. Boden (Eds.) *End-User Development - Is-EUD 2015*. Lecture Notes in Computer Science, Vol. 9083, Springer Verlag, Berlin Heidelberg, 236-241.

Ardito, C., Costabile, M.F., Desolda, G., Matera, M., Piccinno, A. and Picozzi, M. (2012d). Composition of situational interactive spaces by end users: a case for cultural heritage. In *Proc. of the Nordic Conference on Human-Computer Interaction (NordiCHI '12)*. ACM, New York, NY, USA, 79-88.

Ardito, C., Desolda, G., Lanzilotti, R., Malizia, A. and Matera, M. (2017). Advanced Interaction Paradigms to Define Smart Visit Experiences in the Internet of Things Era In *Proc. of the 12th Biannual Conference of the Italian SIGCHI Chapter (CHItaly '17)*, Vol-1910, 1148-1152.

Atzori, L., Iera, A. and Morabito, G. (2010). The Internet of Things: A survey. *The International Journal of Computer and Computer Networks*, 54(15), 2787-2805.

Bangor, A., Kortum, P. and Miller, J. (2008). The system usability scale (SUS): An empirical evaluation. *International Journal of Human-Computer Interaction*, 24(6), 574-594.

Bangor, A., Kortum, P. and Miller, J. (2009). Determining what individual SUS scores mean: Adding an adjective rating scale. *Journal of Usability Studies*, 4(3), 114-123.

Barbieri, G., Celentano, A., Orsini, R. and Pittarello, F. (2009). Understanding Art Exhibitions: From Audioguides To Multimedia Companions. In *Proc. of the International Conference on Distributed Multimedia Systems (DMS '16)*, 250-255.

Bellotti, F., Berta, R., De Gloria, A., D'ursi, A. and Fiore, V. (2013). A serious game model for cultural heritage. *Journal on Computing and Cultural Heritage*, 5(4), 1-27.

Beringer, J. and Latzina, M. (2015). Elastic workplace design. *Designing Socially Embedded Technologies in the Real-World*. Computer Supported Cooperative Work, Vol. Part I, Springer, 19-33.

Brooke, J. (1996). SUS-A quick and dirty usability scale. *Usability evaluation in industry*, 189(194), 4-7.

Brooke, J. (2013). SUS: a retrospective. *Journal of Usability Studies*, 8(2), 29-40.

Cabrera, J.S., Frutos, H.M., oz, Stoica, A.G., Avouris, N., Dimitriadis, Y., Fiotakis, G. and Liveri, K.D. (2005). Mystery in the museum: collaborative learning activities using handheld devices. In *Proc. of the 7th International Conference on Human Computer interaction with Mobile Devices (MobileHCI '05)*. ACM, New York, NY, USA, 315-318.

Casillo, M., Lemma, S., Lombardi, M., De Santo, M. and Colace, F. (2016). A Context-Aware Approach for a Collaborative, Pervasive and Adaptive Digital Storytelling. In *Proc. of the International Conference on Distributed Multimedia Systems (DMS '16)*, 165-174.

Chianese, A. and Piccialli, F. (2014). Designing a Smart Museum: When Cultural Heritage Joins IoT. In *Proc. of the International Conference on Next Generation Mobile Apps, Services and Technologies (NGMAST '14)*. IEEE Computer Society, Washington, DC, USA, 300-306.

Console, L., Antonelli, F., Biamino, G., Carmagnola, F., Cena, F., Chiabrando, E., Cuciti, V., Demichelis, M., Fassio, F., Franceschi, F., Furnari, R., Gena, C., Geymonat, M., Grimaldi, P., Grillo, P., Likavec, S., Lombardi, I., Mana, D., Marcengo, A., Mioli, M., Mirabelli, M., Perrero, M., Picardi, C., Protti, F., Rapp, A., Simeoni, R., Duprè, D.T., Torre, I., Toso, A., Torta, F. and Vernero, F.

(2013). Interacting with social networks of intelligent things and people in the world of gastronomy. *ACM Transactions on Interactive Intelligent Systems*, 3(1), Article 4 (April 2013), 38 pages.
Copeland, T. (2004). Presenting archaeology to the public. In: T. Merriman Ed. *Public Archaeology.* Routledge, London, UK, 132-144.
Coronado, M. and Iglesias, C.A. (2016). Task Automation Services: Automation for the Masses. *IEEE Internet Computing*, 20(1), 52-58.
Costabile, M.F., De Angeli, A., Lanzilotti, R., Ardito, C., Buono, P. and Pederson, T. (2008). Explore! possibilities and challenges of mobile learning. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*. Florence, Italy, ACM,New York, NY, USA,145-154.
Costabile, M.F., Fogli, D., Mussio, P. and Piccinno, A. (2007). Visual Interactive Systems for End-User Development: A Model-Based Design Methodology. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, 37(6), 1029-1046.
Crafty Apps. *Tasker*. Retrieved from http://tasker.dinglisch.net/index.html Last Access Sept 10, 2017.
Damiano, R., Gena, C., Lombardo, V. and Nunnari, F. (2013). Leveraging Web 3D guidance in cultural heritage fruition. In *Proc. of the Conference of the Italian Chapter of SIGCHI (CHItaly '17)*. ACM, New York, NY, USA, 1-10.
Desolda, G., Ardito, C. and Matera, M. (2016). EFESTO: A Platform for the End-User Development of Interactive Workspaces for Data Exploration. In: F. Daniel and C. Pautasso (Eds.) *Rapid Mashup Development Tools - ICWE '15.* Communications in Computer and Information Science, Vol. 591, Springer International Publishing, 63-81.
Desolda, G., Ardito, C. and Matera, M. (2017a). Empowering end users to customize their smart environments: model, composition paradigms and domain-specific tools. *ACM Transactions on Computer-Human Interaction,* 24(2), Article 12 (April 2017), 52 pages.
Desolda, G., Ardito, C. and Matera, M. (2017b). End-User Development for the Internet of Things: EFESTO and the 5W composition paradigm. In: F. Daniel and M. Gaedke (Eds.) *Rapid Mashup Development Tools 2016.* Communications in Computer and Information Science, Vol. 696, 74-93.
Desolda, G., Ardito, C. and Matera, M. (2017c). Specification of Complex Logical Expressions for Task Automation: An EUD Approach. In: S. Barbosa, P. Markopoulos, F. Paternò, S. Stumpf and S. Valtolina (Eds.) *End-User Development, IS-EUD 2017.* Lecture Notes in Computer Science, Vol. 10303, Springer International Publishing, Cham, 108-116.
Díaz, P., Aedo, I. and van der Vaart, M. (2015). Engineering the Creative Co-design of Augmented Digital Experiences with Cultural Heritage. In: P. Díaz, V. Pipek, C. Ardito, C. Jensen, I. Aedo and A. Boden (Eds.) *End-User Development, IS-EUD 2015, Madrid, Spain, May 26-29, 2015.* Springer International Publishing, Cham, 42-57.
Fischer, G., Giaccardi, E., Ye, Y., Sutcliffe, A. and Mehandjiev, N. (2004). Meta-design: a manifesto for end-user development. *Communications of the ACM*, 47(9), 33-37.
Garzotto, F., Gelsomini, M., Clasadonte, F., Montesano, D. and Occhiuto, D. (2016). Wearable Immersive Storytelling for Disabled Children. In *Proc. of the International Conference on Advanced Visual Interfaces (AVI '16)*. ACM, New York, NY, USA, 196-203.
Gatto, I. and Pittarello, F. (2014). Creating Web3D educational stories from crowdsourced annotations. *Journal of Visual Languages & Computing*, 25(6), 808-817.
Ghiani, G., Manca, M., Paternò, F. and Santoro, C. (2017). Personalization of Context-Dependent Applications Through Trigger-Action Rules. *ACM Transaction on Computer-Human Interaction*, 24(2), Article 14 (April 2017), 33 pages.
Grisaffe, D.B. (2007). Questions about the ultimate question: conceptual considerations in evaluating Reichheld's net promoter score (NPS). *Journal of Consumer Satisfaction, Dissatisfaction and Complaining Behavior*, 20, 36.
Hamilton, P. and Wigdor, D.J. (2014). Conductor: enabling and understanding cross-device interaction. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 2773-2782.
Hart, S.G. and Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. *Advances in Psychology*, 52, 139-183.
Hinrichs, U., Schmidt, H. and Carpendale, S. (2008). EMDialog: Bringing Information Visualization into the Museum. *IEEE Transactions on Visualization and Computer Graphics*, 14(6), 1181-1188.
Hsi, S. and Fait, H. (2005). RFID enhances visitors' museum experience at the Exploratorium. *Communication of the ACM*, 48(9), 60-65.
IFTTT Inc. *IFTTT*. Retrieved from https://ifttt.com/ Last Access Sept 10, 2017.
Ishii, H. and Ullmer, B. (1997). Tangible bits: towards seamless interfaces between people, bits and atoms. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems (CHI '97)*. ACM, New York, NY, USA, 234-241.
Itrios LLC. *itDuzzit*. Retrieved from http://cloud.itduzzit.com/ Last Access Sept 10, 2017.
Korzun, D., Varfolomeyev, A., Yalovitsyna, S. and Volokhova, V. (2017). Semantic infrastructure of a smart museum: toward making cultural heritage knowledge usable and creatable by visitors and professionals. *Personal and Ubiquitous Computing*, 21(2), 345-354.
Kuflik, T., Stock, O., Zancanaro, M., Gorfinkel, A., Jbara, S., Kats, S., Sheidin, J. and Kashtan, N. (2011). A visitor's guide in an active museum: Presentations, communications, and reflection. *Journal on Computing and Cultural Heritage*, 3(3), 1-25.
Kuflik, T., Wecker, A.J., Lanir, J. and Stock, O. (2015). An integrative framework for extending the boundaries of the museum visit experience: linking the pre, during and post visit phases. *Information Technology & Tourism*, 15(1), 17-47.
Lanir, J., Kuflik, T., Sheidin, J., Yavin, N., Leiderman, K. and Segal, M. (2017). Visualizing museum visitors' behavior: Where do they go and what do they do there? *Personal and Ubiquitous Computing*, 21(2), 313-326.

Lanir, J., Wecker, A.J., Kuflik, T. and Felberbaum, Y. (2016). Shared mobile displays: an exploratory study of their use in a museum setting. *Personal and Ubiquitous Computing*, 20(4), 635-651.

Latzina, M. and Beringer, J. (2012). Transformative user experience: beyond packaged design. *interactions*, 19(2), 30-33.

Lewis, J. and Sauro, J. (2009). The Factor Structure of the System Usability Scale. In: M. Kurosu Ed. *Human Centered Design - HCD 2009.* Lecture Notes in Computer Science, Vol. 5619, Springer Berlin Heidelberg, 94-103.

Lieberman, H., Paternò, F., Klann, M. and Wulf, V. (2006a). End-User Development: An Emerging Paradigm. In: H. Lieberman, F. Paternò and V. Wulf (Eds.) *End User Development.* Human-Computer Interaction Series, Vol. 9, Springer Netherlands, 1-8.

Lieberman, H., Paternò, F. and Wulf, V. 2006b. *End User Development*. Springer.

Manches, A. (2011). Digital manipulatives: tools to transform early learning experiences. *Internation Journal of Technology Enhanced Learning*, 3(6), 608-626.

Merriman, T. 2004. *Public Archaeology*. Routledge, London, UK.

Mighali, V., Fiore, G.D., Patrono, L., Mainetti, L., Alletto, S., Serra, G. and Cucchiara, R. (2015). Innovative IoT-aware Services for a Smart Museum. In *Proc. of the International Conference on World Wide Web (WWW '15)*. ACM, New York, NY, USA, 547-550.

Mokatren, M., Kuflik, T. and Shimshoni, I. (2016). A novel image based positioning technique using mobile eye tracker for a museum visit. In *Proc. of the International Conference on Human-Computer Interaction with Mobile Devices and Services, in Adjunct proceedings (MobileHCI '18)*. ACM, New York, NY, USA, 984-991.

NodeMcu Team. *NodeMcu*. Retrieved from http://nodemcu.com/index_en.html Last Access Sept 10, 2017.

Not, E., Peterelli, D., Stock, O., Strapparava, C. and Zancanaro, M. (1997). Person-Oriented Guided Visits in a Physical Museum. In *Proc. of the International Conference on Hypermedia and Interactivity in Museums (ICHIM '97)*. Archives & Museum Informatics, Le Louvre, Paris, France, 69-79.

Not, E., Zancanaro, M., Marshall, M.T., Petrelli, D. and Pisetti, A. (2017). Writing Postcards from the Museum: Composing Personalised Tangible Souvenirs. In *Proc. of the Biannual Conference on Italian SIGCHI Chapter (CHItaly '17)*. ACM, New York, NY, USA, 1-9.

Pane, J.F., Ratanamahatana, C.A. and Myers, B.A. (2001). Studying the language and structure in non-programmers' solutions to programming problems. *International Journal of Human-Computer Studies*, 54(2), 237-264.

Petrelli, D., Ciolfi, L., Dijk, D.v., Hornecker, E., Not, E. and Schmidt, A. (2013). Integrating material and digital: a new way for cultural heritage. *interactions*, 20(4), 58-63.

Petrelli, D. and Lechner, M. (2014). The meSch project – Material EncounterS with digital Cultural Heritage: Reusing existing digital resources in the creation of novel forms of visitor's experiences. In *Proc. of the International Committee for Documentation of ICOM (CIDOC '14)*.

Petrelli, D., Marshall, M.T., O'Brien, S., McEntaggart, P. and Gwilt, I. (2017). Tangible data souvenirs as a bridge between a physical museum visit and online digital experience. *Personal and Ubiquitous Computing*, 21(2), 281-295.

Piccialli, F. and Chianese, A. (2017a). The Internet of Things Supporting Context-Aware Computing: A Cultural Heritage Case Study. *Mobile Networks and Applications*, 22(2), 332-343.

Piccialli, F. and Chianese, A. (2017b). A location - based IoT platform supporting the cultural heritage domain. *Concurrency and Computation: Practice and Experience*, 29(11).

Rapp, A., Cena, F., Console, L., Gena, C. and Marcengo, A. (2016). A Field Evaluation of an Intelligent Interaction Between People and a Territory and its Cultural Heritage. In *Proc. of the Workshop on Advanced Visual Interfaces for Cultural Heritage (AVI*CH '16)* CEUR-WS, Vol-1621, 1611-1614.

Risseeuw, M., Cavada, D., Not, E., Zancanaro, M., Marshall, M., Petrelli, D. and Kubitza, T. (2016). An authoring environment for smart objects in museums: the meSch approach. In *Proc. of the Workshop on Smart Ecosystems cReation by Visual dEsign (SERVE '16)* CEUR-WS, 1602, 25-30.

Rogers, Y., Sharp, H. and Preece, J. 2015. *Interaction Design: Beyond Human - Computer Interaction*. Wiley.

Sintoris, C., Stoica, A., Papadimitriou, I., Yiannoutsou, N., Vassilis, K. and Avouris, N. (2010). MuseumScrabble: Design of a mobile game for children's interaction with a digitally augmented cultural space. *International Journal of Mobile Human-Computer Interaction*, 2(2), 53-71.

SmarterApps Ltd. *AutomateIt - Smart Automation*. Retrieved from http://automateitapp.com/ Last Access Sept 10, 2016.

Stock, O. and Zancanaro, M. 2007. *PEACH - Intelligent Interfaces for Museum Visits (Cognitive Technologies)*. Springer-Verlag New York, Inc.

Tutenel, T., Bidarra, R., Smelik, R.M. and Kraker, K.J.D. (2008). The role of semantics in games and simulations. *Computer Entertainment*, 6(4), 1-35.

Vanacken, L., Raymaekers, C. and Coninx, K. (2007). Introducing semantic information during conceptual modelling of interaction for virtual environments. In *Proc. of the Workshop on Multimodal Interfaces in Semantic Interaction (WMISI '07)*. ACM, New York, NY, USA, 17-24.

Vom Lehn, D. and Heath, C. (2003). Displacing the object: mobile technologies and interpretive resources. *Archives & Museum Informatics*, 2.

Wecker, A.J., Kuflik, T. and Stock, O. (2017). AMuse: Connecting Indoor and Outdoor Cultural Heritage Experiences. In *Proc. of the International Conference on Intelligent User Interfaces Companion (IUI '17)*. ACM, New York, NY, USA, 153-156.

WigWag Inc. *WigWag Smart Home*. Retrieved from http://www.wigwag.com/ Last Access Sept 10, 2017.

Yannier, N., Hudson, S.E., Wiese, E.S. and Koedinger, K.R. (2016). Adding Physical Objects to an Interactive Game Improves Learning and Enjoyment: Evidence from EarthShake. *ACM Transaction on Computer-Human Interaction*, 23(4), Article 26 (September 2016), 32 pages.

Zancanaro, M., Not, E., Petrelli, D., Marshall, M., van Dijk, T., Risseeuw, M., van Dijk, D., Venturini, A., Cavada, D. and Kubitza, T. (2015). Recipes for tangible and embodied visit experiences. In *Proc. of the Museums and the Web conference (MW '15)*.