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## From Smart Objects to Smart Visit 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 technology by end users. This lack limits the social and practical benefits of IoT; it creates barriers in all those usage scenarios where domain-experts are required to define the behavior of smart objects but they might not have any skill in programming. 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 therefore presents a visual composition paradigm that allows non-programmers to synchronize the behavior of smart objects. It also discusses how the paradigm suites the need of curators and guides of CH sites to define *smart visit experiences* where visitors can acquire CH content by interacting with the surrounding environment and a number of 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.

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### 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 to 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. 2012b; Stock and Zancanaro 2007], including large displays (see [Ardito et al. 2015a; Hinrichs et al. 2008]). The Internet of Things (IoT) has recently emerged as a very promising technology able to enhance the access to CH collections. It is based on distributed services that enable the access through the Internet 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 monitoring system). Through this technology, it is possible to create objects that visitors of CH sites can bring with themselves, touch and manipulate for experiencing the museum by receiving personalized information [Petrelli and Lechner 2014; Risseeuw et al. 2016; Zancanaro et al. 2015]. The interaction with such tangible objects favours 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 some issues to be solved to increase its practical impact. The growing availability of smart objects has in general stimulated researchers to investigate the IoT phenomenon from different perspectives. However, also 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]. Very few approaches try to facilitate the configuration of smart objects, but the advantage they introduce is limited to programming easily single objects that the visitors bring across the CH site to receive personalized content when they reach some interactive hot spots [Petrelli and Lechner 2014]. It is still hard to synchronize the behavior of multiple devices, 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 events. It is even harder to let non-technical people define such visit experiences.

This shortage creates barriers in all those scenarios where domain-experts, not necessarily experts in programming, would take advantage from defining by themselves the behavior of smart spaces. One such domain is certainly CH, as guides and curators could need to combine the behavior of IoT devices to improve content appropriation by visitors. To fill this gap, this article discusses an End-User Development approach that, by means of a visual composition paradigm, allows non-programmers to define smart experiences by synchronizing 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. 2006], End-User Development (EUD) methodologies fit very well the requirement of letting end users customize systems to support situational needs.

Our visual composition paradigm can support CH sites professionals in defining *smart visit experiences*, i.e., situations within CH sites where visitors can interact with the surrounding environment by means of smart devices installed in it, to pursue some learning goals and acquire the CH content. 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 *sensible attributes* that the end users themselves (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 can be put in context with respect to the CH site content. The EUD paradigm also offers the possibility to adapt easily such narratives to different visitors and different types of smart experiences with the CH site content.

This article discusses some 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 was based on the outcomes of studies performed to analyze, in real conditions, the potentials and limitations of our approach. A series of studies involved six professional guides of different CH sites in the Apulia region, Southern Italy: two guides of archaeological parks, one guide of Natural Science museums and three guides of a wildlife park. 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, and illustrates the motivations that led us to extend our previous platform for the EUD of IoT systems to augment smart devices and objects with semantic attributes. This section also reviews some prominent approaches that, in line with our research, aim to facilitate the adoption of smart devices and objects within CH sites. 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 therefore describes such abstractions as the main ingredients of a composition paradigm for smart visit experiences. Section 5 illustrates the resulting visual composition paradigm as it was implemented in the new platform prototype, EFESTO-4SE (EFESTO for Smart Experiences). Section 6 reports on a formative evaluation conducted with four professional guides to validate the implemented composition paradigm with respect to the mental model of the platform 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 Web sites, mobile apps and interactive displays to present to enhance the presentation of the content exhibited in a given site. 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.

Providing personalized visit experiences is however 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 support visit experiences that respond to situational needs, 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 adopted by themselves and by visitors. We therefore exploited Web service technology and defined an End-User Development framework [Ardito et al. 2014b] used to create a platform that allows domain experts, who are not technologically skilled, to extract contents from heterogeneous (personal or third-party) sources, and mash them up to compose “on-the-fly” interactive workspaces integrating resources useful for enhancing the visit. The platform is characterized by a visual paradigm for extracting content and composing it in interactive workspaces. The resulting workspaces can then be ubiquitously distributed across different devices, including visitors’ personal devices. Various users 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 people visiting cultural heritage sites [Ardito et al. 2014a; Ardito et al. 2014b].

Following the trend toward a massive use of smart objects, we recently extended our platform to flexibly compose IoT devices [Desolda et al. 2017a]. We defined a visual 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. With respect to our previous work, 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 user interaction with smart objects mediates the access to CH content.

CH is watching with interest the IoT technologies. Some works show that the interaction with tangible objects favors emotions and engagement [Petrelli and Lechner 2014], as physical manipulative 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 favour the definition of *custom properties* associated to smart devices. The designers of the interactive experience can thus make sense of low-level events and actions to contextualize the use of smart devices in narrative scenarios supporting personalized fruitions of content.

The need for higher-level abstractions is already evident in some works that aim to support CH experts in designing interactive visit experiences based on serious games [Bellotti et al. 2013]. Some proposals in this direction adopt ontologies and semantics [Tutenel et al. 2008] to give operational meanings to the objects in the virtual words a game consists of. This allows the experts to focus better on the specifics of the cultural domain, more than on the technicalities of a virtual word definition [Vanacken et al. 2007]. In this article, we show how, by means of adequate visual notations, the CH experts themselves can define custom properties through which they can make sense of the available smart devices for the design of a visit experiences.

Before describing our approach, in the rest of this section we discuss some relevant 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 curators and professional guides.

### 2.1. IoT Technologies in CH sites

A substantial amount of work has been carried out about how to exploit technologies to offer more engaging experiences of cultural heritage (e.g., [Cabrera et al. 2005; Copeland 2004; Not et al. 1997; Sintoris et al. 2010; Stock and Zancanaro 2007]). A wealth of digital content is currently available in online repositories, portals or on museum servers. Such content is mainly exploited through static delivery paradigms. Most work is indeed related to the use of Web technology to provide information about museums, historical sites, events, in some cases creating virtual reality reconstructions of specific exhibitions (see for example [Ardito et al. 2007; Bellotti et al. 2013]). Mobile technology has also been largely employed to support museum visits since its early stage [Ardito et al. 2012c; Hsi and Fait 2005]. In many cases, visitors are provided with multimedia companions that try to improve the overall visitors' experience using audio, video and textual information. Some approaches also take into account the needs of people with different expectations and abilities in using mobile devices [Antonioni and Lepouras 2010; Kuflik et al. 2011].

The literature is full of several other contributions. However, one still scarcely unexplored form of visit is to let visitors interact with digital content through a physical engagement with the exhibits. The interaction with tangible objects support visitors to put information in context without any effort to interact with apps and touch screens [Risseuw et al. 2016]. Smart objects favor the so-called *tangible thinking*, that is the ability to think by means of the physical manipulation of objects augmented with digital information or properties [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 mostly 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 [Mighali et al. 2015] the authors then describe how to design a processing server for providing Web services for the CH visitors that seamlessly combine IoT devices, mobile and wearable devices, and to permit the access to digital content available on the cloud. Such works are fundamental to investigate the technical feasibility of installing smart devices and related services within CH sites. However, once technology is in place, it is also important to facilitate the definition of smart visit experiences 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 developed *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 thus 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 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 the identification of 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 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

In relation to the configuration by CH experts of smart visit experiences, there are very few contributions in the literature. 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]. 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; Risseuw 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 cultural heritage stakeholders in the design of the visit experience. This work is very interesting also because of the large experimentation conducted with the help of 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 makes valuable the experience with smart objects within a cultural heritage site, and how this experience 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. CODICE is thus a platform to share different ideas and to store outcomes to help different CH actors to reflect upon digital solutions. One of the outcomes resulting from 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] focusing 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 of 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 the designers of a smart experience contextualize ECA rules with respect to the content and learning goals of narratives for smart visit experiences.

### 3. Elicitation study

The main goal of our research is to provide end users, who have not skills in programming, with interactive tools to create smart experiences by managing ecosystems of interoperable smart objects. The paradigm for ECA rule specification that we implemented in the EFESTO-5W platform was considered usable and useful in scenarios where the rules defined by end users have a semantics that is strictly related to the 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). Also, 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 with respect to a given goal.

In relation to the definition of smart experiences, we realized that some extensions were needed to express semantics to: *i*) contextualize the use of smart objects and related synchronization rules with respect to a content characterizing the experience and, *ii*) make explicit possible relations among objects and rules with respect to this content. Smart visit experiences are indeed characterized by the provision of content in a

narrative. Thus, they may consist of the progressive activation of different rules, and of evolving states of the environment, that in the end lead to the discovery of content for the achievement of some learning goals. If characterized by some semantics related to the content of the CH site, ECA rules and the evolving states of the environment could be easily identified and managed by CH site 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. The TUX goal is to respond to the users' situational needs by enabling user interaction with information by means of dedicated task-based contexts. In the TUX terminology, these contexts are called *containers*, as they “group” items that are transformed according to the semantics of the task they refer to. TUX indeed promotes the adoption of mechanisms that allow the user, who wants to access some information, to confer different capabilities to data. 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 contexts the data pass through. Transitions among different contexts elastically modify capabilities of the involved objects, which are 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 now shown as a pin on the map in the position where it has been rediscovered. The path from the current user location to the rediscovery place is also automatically calculated and depicted on the map. The user is given the role of governing the transitions among different containers, depending on the current usage situation and on the functionality (e.g., data manipulations) they need to further proceed with their task.

Inspired by this framework, we promote the notion of *custom attributes* as conceptual tools that can allow smart experience 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 to the smart experience beneficiaries.

In the rest of this section, we will report on a study that allowed us to assess if associating such semantics to smart objects and rules is feasible by CH professional guides and can be considered a solution to facilitate the definition of smart visit experiences. The study did not focus on the visual elements of the composition paradigm; rather it tried to investigate the usefulness of adding additional semantics as a way to transform smart objects from devices generating signals to objects contributing to the visit narrative by means of their custom attributes.

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 an interactive visit experience that included ICT and IoT devices. Then, they had to work at assigning semantics to the objects, devices and services involved in the scenario they designed with the aim of facilitating the use of such components within the smart visit experience. Finally, they had to define, very informally, the rules for controlling the component behavior.

### 3.1. 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 technology for supporting their work activities, but had no experience with managing IoT elements.

### 3.2. Procedure

The study was performed 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 in group. The study procedure was the same in the three meetings, as described in the following. 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 and working 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. A couple of typical examples illustrated to participants were: 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: *Achille 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. Achille 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. Achille would improve the visit efficacy 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 sea. It's Summer time and many families conclude their day at the beach by joining one of the guided tour he offers 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 interactive visit experience narrative; 2) identification of a set of smart objects involved in the interactive 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 in 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.

### 3.3. 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, and the rules controlling the objects; 5) to the answers participants gave to the questionnaire.

The two researchers transcribed their notes and the audios, and independently double-checked 65% of the material. The initial reliability value was 81%; thus, the researchers discussed the differences and reached a full agreement. The transcripts were analyzed through a thematic analysis following a semantic approach. Themes were identified within the explicit or surface meaning of the data [Braun and Clarke 2006b]. The two questionnaire open questions were analyzed through the affinity diagram technique proposed in [Rogers et al. 2015].

### 3.4. Results of scenario design

A total of 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

*Achille 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, Achille wants to use also a reproduction of the "Mouth of Truth"\*.* During the tour, Achille 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 the right answer. If they are successful, 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, provided examples of possible values of the attribute as in the "Attribute instance example" column. Finally, he provided, in the "Attribute explanation" column, a description of the semantics

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\* 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.

of the attribute in the designed scenario.

Table 1. Scenario objects characterization provided by the archaeological park guide.

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

Finally, the guide defined the following rules:

1. “When a team member puts a card in the guide’s device and the device *Modality* is *Location matching*, if the *Place* of the card matches the device *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 *Age* attribute of the card matches the *Age* set through the device buttons, 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<sup>†</sup> 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 another 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 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

<sup>†</sup> According to Dictionary.com: *biome* is a complex biotic community characterized by distinctive plant and animal species and maintained under the climatic conditions of the region, especially such a community that has developed to climax.

*short video documentary about the biome is proposed through the tablet display.*

The natural science museum guide identified the following objects, as 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 characterization provided by the natural science museum guide.

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

Finally, 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* of the card matches the Guide Device *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 is starting to organize the tours inside the Torre Guaceto park 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 the 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. Or visitors can measure air parameters by attaching the sphere to a kite that they have 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 guide identified the following objects, as reported in Table 3: a sensor device to measure water, air and ground parameters, and a mobile device.

Table 3. Scenario objects characterization provided by the wildlife park guide.

Scenario object	Custom Attribute name	Attribute value examples	Attribute explanation
Sensor device	Name	<i>Magical ball</i>	Name assigned to the device used for measuring environmental parameters
	Modality	<i>Air, Water, Ground</i>	Modality in which the device measure a specific type of parameters
	Position	<i>Canal, Lake, forest</i>	Place where the device is currently located
Mobile device	Device name	<i>Visitor's tablet</i>	Name assigned to the device carried by the visitors
	Modality	<i>Air, Water, Ground</i>	Measure modality; based on it the mobile device controls proper sensors measuring a specific type of parameters

Finally, the guide defined the following rule:

1. “If a visitor sets the mobile device in a *Modality* and taps the *Measure* button, then switch the Sensor device in the corresponding *Modality* and save the measured values”.

### 3.5. Results from the 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 3.1. The understanding of and comfort with study procedure and proposed tasks was rated 2.5 out of 7 (lowest is better). Regarding the advantages expressed in the open questions, participants reported 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 are required to identify which smart objects for building their smart experience.

#### 4. Characterizing the 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 through which domain experts (i.e., the end user of our EUD platform) are enabled to define *smart experiences*. Figure 1 schematically represents the main conceptual elements and the way they relate to each other. For the smart experience to be held, we assume that some *resources*, which can be *Smart Objects* or also *Web Services*, are available and expose *events* and *actions*. With respect to the scenarios described in the previous section, we also consider Web services as they can offer access to complementary data or to some functionality needed to manage the overall logic of the smart experience. For example, even if not explicitly highlighted by the guides taking part to the study, a *Game Engine* Web service would be needed to manage the scores to be assigned to the different teams during the game. We will explain the way this service works in the following examples.

Any resource, being it a smart object or a Web service, is characterized by a set of *events* it is able to detect and a set of *actions* it is able to perform. 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 synchronizing resources. Defining synchronized behaviors is indeed a fundamental feature for the creation of smart experiences.

It is worth noting that we focus on situations where smart experience participants could also be source of events and actions. We however 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 as well are 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 Mouth of Truth device). Therefore, we consider the *smart experience* as a set of ECA rules configuring and synchronizing the behavior of smart objects and Web services.

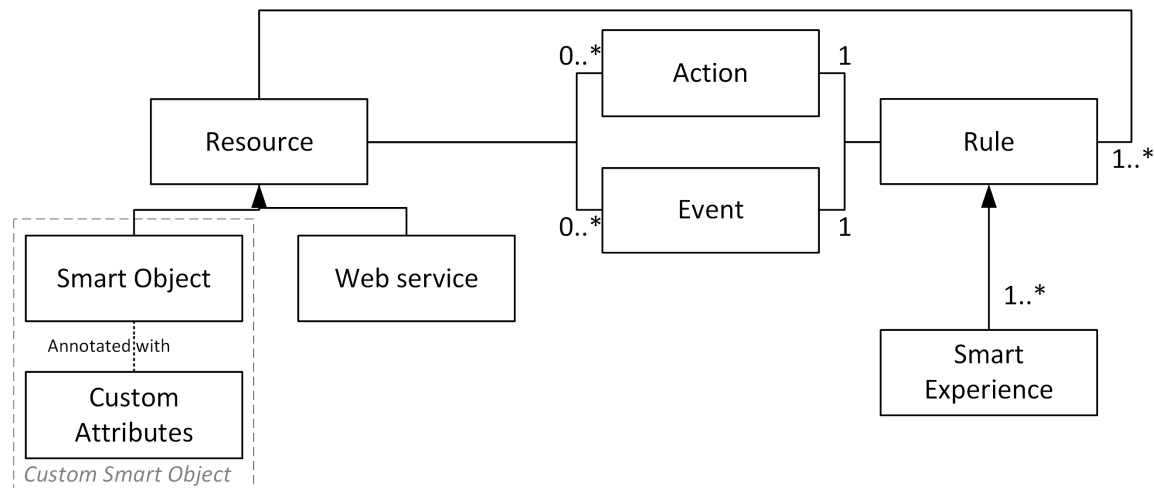


Figure 1. A schematic representation of the main conceptual elements to compose smart experiences.

Let us now define in more detail the concepts represented in Figure 1. While giving definitions, we will refer to the Scenario 1 reported in 3.4 (Achille's scenario) to provide concrete examples.

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

In the Achille's scenario, *Re* consists of the two smart objects *Team Card* and *Guide Device*. A Web service, *Game Engine*, is also exploited as additional resource to control the game dynamics, for example to update team scores. *Ru* then includes the two rules reported in Section 3. Such rules, initially expressed in natural language, can be codified according to a more formal ECA representation that we will introduce below.

**Definition 2. Web service.** A *Web service* is a software resource providing access to a remote or local service that offers data and/or functionality by means of the operations. A Web service, *ws*, is characterized by events and actions:

$$ws = \{Events, Actions\}$$

For example, the *Game Engine* Web service in the Achille's scenario is characterized by the following sets:

$$Events = \{getPoints?team=targetTeam, winningTeam?team=targetTeam\}$$

$$Actions = \{AssignPointToTeam?point=pointsToBeAssigned\&team=targetTeam\}$$

The two events are both generated by changes in the score assigned to a team (represented by the variable *targetTeam*), which occur when the team gains additional points, and when the team reaches a score that makes it win. The action then increases the team's score, for example when the event *getPoints?team=targetTeam* occurs.

**Definition 3. Smart Object.** It is the logical representation of a physical device used in the real world. Typically, a smart object is a micro-controller equipped with sensors that can "feel" events and/or actuators able to execute actions. Our approach specifically aims to enrich this technical perspective; therefore, a smart object can be abstracted as an entity characterized by three different elements:

$$so = \langle Events, Actions, Custom Attributes \rangle$$

Figure 2 reports instances of these three elements for the two smart objects in the Achille's scenario, namely, the *Guide Device* and the *Team Card*.

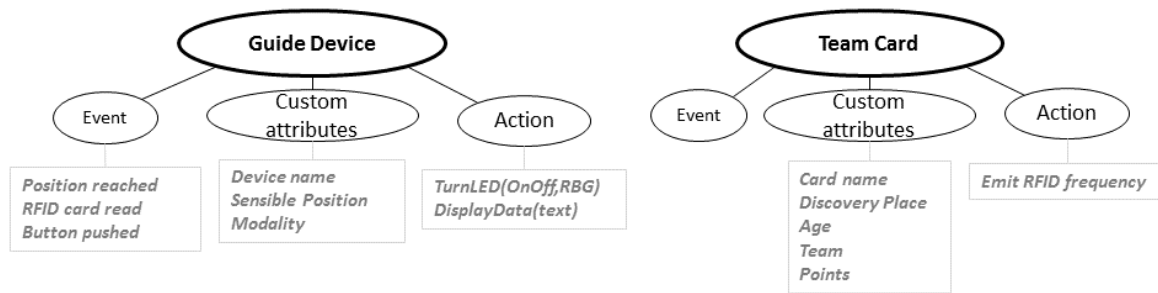


Figure 2. Models of the smart objects involved in the Achille's scenario.

We now define in more details *events*, *actions* and *custom attributes*.

**Definition 4. Event.** It represents a state change that a resource is able to detect. Changes can occur in data produced by the surrounding environment (e.g., the temperature in a room), or on data retrieved through Web services (e.g., the meteorological conditions in the archaeological park area). If sensors are embedded in smart objects manipulated by the smart experience participants (e.g., the visitors of a CH site), *Events* can also refer to participants' actions within the environment. For example, the event "Position Reached" represented in Figure 2 for the guide device actually refers to sensing a situation in which the visitor reaches a given position in the site. Similarly, the events "RFID card read" and "Button Pressed" refer to the visitor actions of respectively putting a card with a given ID close to the guide device and pressing a button of the device. There might be smart objects that do not expose events. This is the case of the Team Card device, as RFID cards are not able to sense any event; rather their RFID frequency can be detected by a reader as the one embedded within the Guide Device.

**Definition 5. Action:** As reaction to the sensed events, *Actions* refer to the set of functions that a smart object can actuate through its actuators or a Web services can perform through its operations. Actions for the Guide Device smart object in Figure 2 are "TurnLED(OnOff, RGB)" or "DisplayData(text)". The object is indeed supposed to blink its led when the visitors answer correctly to some questions, or to display a text reporting the score reached by a team. The Game Engine Web service then exposes the action already reported in Definition 2.

**Definition 6. 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. Custom attributes apply both the smart objects and Web services. We here however focus on the way they extend the notion of smart objects, by representing additional properties, related to or independent of events and actions, which the designer defines to make sense of the object within the smart experience context. Each custom attribute, *ca*, can be defined as:

$$ca = \langle name, V \rangle$$

to indicate that its definition consists in specifying *values* (the elements of the set *V*) that the variable represented by a given *name* can hold in the context of the smart experience.

The attributes specified in Table 1 for the Achille's scenario all correspond to custom attributes that augment the semantics of the involved smart objects. The criterion for choosing a specific attribute to augment smart object 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. For example, in our reference scenario Achille associates a “Name” to the cards given to the visitors (“amphora”, “coin”, “musical instrument”), to distinguish among the different objects the cards will refer to during the visit. 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 Achille 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  $ca_i$  to a smart object  $so_j$  then consists of specifying the values that make sense for  $ca_i$  in relation to the use of  $so_j$  in a given smart experience. In other words, the association produces annotations of type  $\langle ca_i, v_k, so_j \rangle$ , meaning that  $so_j$  inherits the attribute  $ca_i$  with the  $v_k$  value. Thus  $ca_i$  becomes one attribute exposed by  $so_j$  that: *i*) it can be exploited at design time to define conditions within ECA rules and *ii*) it can be evaluated during the execution of the smart experience to assess whether  $so_j$  reached some sensible states. For example, in our reference scenario, Achille annotates the *Card* objects with the attribute *Age*, and he associates different values to the different cards, thus creating triples like  $\langle \text{Age}, \text{Roman time}, \text{team card 1} \rangle$ ,  $\langle \text{Age}, \text{Roman time}, \text{team card 2} \rangle$ ,  $\langle \text{Age}, \text{Messapian time}, \text{team card 3} \rangle$ .

**Definition 7: Rule.** A rule combines events and actions exposed by the involved resources to determine the activation of some behavior when some events are detected. It is a synchronization mechanism among different resource that users define according to an event-driven, publish-subscribe integration logic. The users define that, when some events are detected on one or more resources and satisfy specific conditions, actions will be performed by the same or different resources. In our approach, rule conditions can also be expressed in terms of CA defined on the involved smart objects. A rule can be defined as a pair:

$$r = \langle \text{eventConditions}, \text{conditionedActions} \rangle$$

where:

- *eventConditions* is any logic expression that combines conditions over the occurrence of events through the logical operators AND and OR. Conditions can also include temporal and spatial constraints. Given our characterization of smart objects, conditions can have as arguments both *Events* and *CustomAttributes* exposed by a smart object.
- *conditionedActions* is any logic expression that combines actions that can be executed by the involved resources through the logical operators AND. The execution of actions can also be constrained by temporal and spatial constraints. Given our characterization of smart objects, custom attributes can be used as arguments of the condition or as target of the action.

According to this definition, the rules of the Achille’s scenario become:

$$r_1 = \langle (\text{GuideDevice.RFID card Read AND GuideDevice.Modality is equal to LocationMatching AND GuideDevice.positionReached is equal to TeamCard.DiscoveryPlace}), (\text{GameEngine.AssignPointToTeam}(\text{RFID card.Points}, \text{RFID card.Team})) \rangle$$

$$r_2 = \langle (\text{GuideDevice.RFID card Read AND GuideDevice.Modality is equal to AgeMatching AND GuideDevice.Pushed Button is equal to TeamCard.Age}), (\text{GameEngine.AssignPointToTeam}(\text{RFID card.Points}, \text{RFID card.Team})) \rangle$$

Being it possible to have Web services as resources, actions used in a rule can also be operations exposed by a software service. The action specified in the previous two rules is indeed the operation exposed by the



Game Engine Web service (see the example of Definition 2). In general, the rules defined to govern the smart experience can produce state changes at different levels. They may impact on the environment where the experience takes place (e.g., the lights of a room are switched on), on devices (e.g., TurnOnRGBled(R,G,B) on the Guide Device smart object), or on software services that might also change the value of custom attributes associated to a smart object (e.g., increase the score of a Team holding a card).

## 5. Enabling the Definition of Smart Experiences

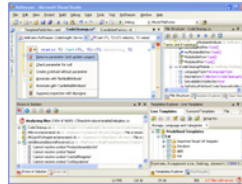
In this section, we describe how Achille would create the smart experience described in “Scenario 1 - A game in the archaeological park of Egnathia” (see Section 3.4). Overall, he needs to create the smart experience resources (i.e., smart objects and/or Web services) and then configure and synchronize their behavior using the EFESTO-4SE (EFESTO 4 Smart Experiences) platform. EFESTO-4SE implements the model described in the previous section. 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-4SE 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.

The entire process for defining a smart experience is driven by a three-layer meta-design model we developed to foster the adoption of interactive systems in specific domains [Ardito et al. 2014b], and here extended for developing smart experiences (see Figure 3). Meta design means “design for designers” and prescribes involving domain and/or technology experts to 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 on 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* of Figure 3, professional developers (e.g., makers or IoT 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 that respond to the requirements of the domain in which the smart experience has to be developed and 2) registering and configuring such resources. Such collaboration is essential for a successful customization that prepares the platform for the use in a given domain. With reference to the results of the elicitation study (see Section 3.5), it can for example help CH guides understand exactly what behavior the smart objects can actually expose. For example, in the Achille’s scenario the main resources of the smart experiences are the Mouth of Truth, the RFID cards and the Game Engine Web service. Such resources are developed respectively by makers and IT experts who know how to program them. Achille, acting as domain expert, collaborates with them to register and configure in EFESTO-4SE those elements of the smart objects that actually make sense in the smart experience he wants to define. After the customization of EFESTO-SE4, Achille (or any other guide who wants to create a similar visit experience) will see the smart objects, the Web services, and all their events, actions, and custom attributes, as components that can be used to define rules governing the smart experience he aims to design. In our model, the creation of the smart experience is a mix of use and design activities positioned at the *bottom-layer* of Figure 3. At this layer, the end users (e.g., Achille in our scenario) *use* the customized platform to *design* the smart experiences to be proposed to the final participants.

It is worth noting that whenever the tools available in the platforms do not satisfy the requirements of the smart experience under design, the end users can refer to the stockholders at the upper layers. For example,

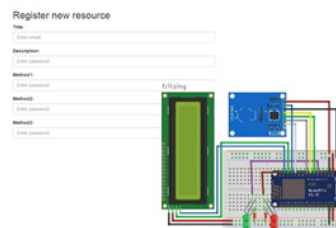
during the development of his smart experience, Achille can have the need to introduce new functionality in the MoT, for example the possibility to emit sounds when the card is read. Thus, he communicates this new need to the stakeholders of the upper layer, which are in charge of integrating this new feature. The maker thus adds a speaker inside the MoT and the professional developer configures and registers such a new actuator in the platform. From that moment on, Achille can use the speaker when defining the ECA rule, for example to emit sounds associated to the read card.

### Professional developers



Integrated development environments (IDEs) for implementing software environments for other stakeholders

### Collaboration among Domain experts Professional developers Makers



3D printers, microcontrollers, sensors and actuators for building smart object

Platform environment for:

- Programming smart objects
- Resource registration
- Resource configuration

### End users



Platform environments for smart experience design:

- Custom attribute definition
- ECA rules creation

Figure 3. A three-layer meta-design model that supports the creation of smart experiences.

In the following, we describe in details how the makers build the Mouth of Truth and the other smart objects (Section 5.1), how the IT experts develop the Game Engine (Section 5.2), and how such resources are registered and configured in EFESTO-4SE (Section 5.3). Afterwards, we illustrate how Achille use EFESTO-4SE to build the interactive experience by creating custom attributes and ECA rules (Section 5.4).

#### 5.1. Building the Smart Objects

Achille needs a “Mouth of Truth” (MoT), a smart device with the capability to connect to the Internet, read smart cards (user input), show messages on a display and blink the eyes. Since such an object does not exist yet and Achille is not an ICT expert, he goes to a makerspace in his city, where the makers build the MoT device shown in Figure 4.

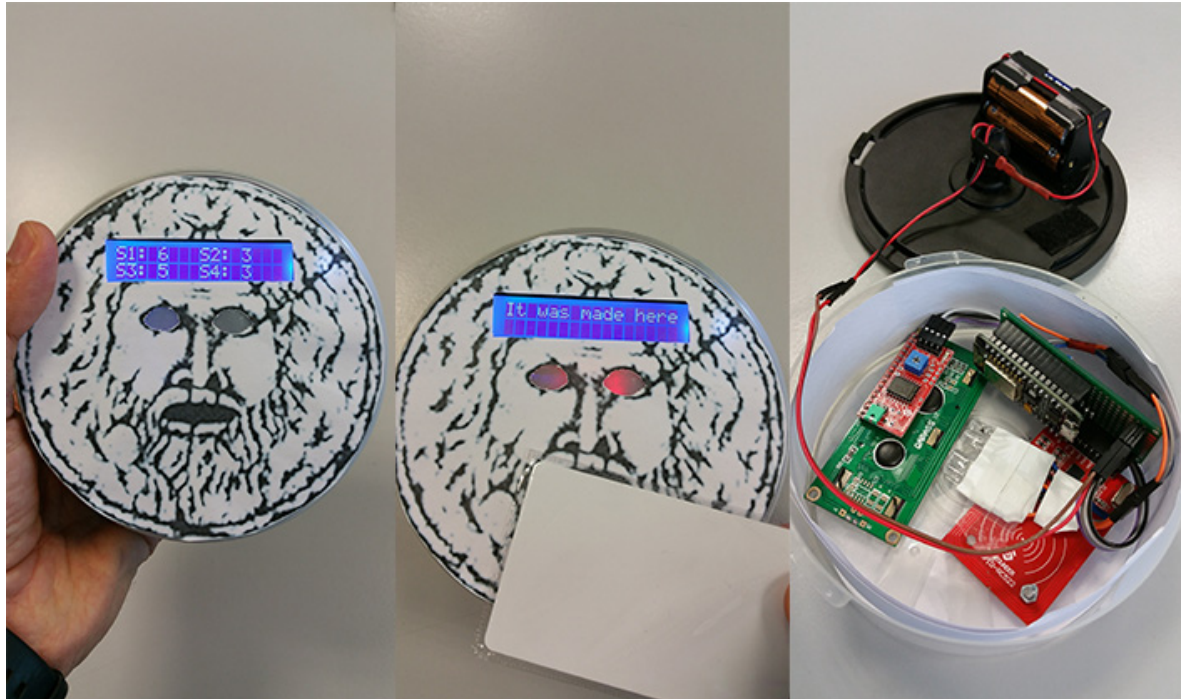


Figure 4. The Mouth of Truth smart object built to develop the scenario “game in the archaeological park”

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 sensor and actuators and determines the MoT functionality [NodeMcu\_Team 2016]. 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. In addition, 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.

Afterwards, the makerspace prints the pictures related to the Egnathia provided by Achille and attaches them on cards provided with an RFID tag. Then they register the MoT and the RFID cards in a cloud provider to publish a set of RESTful methods, in order to remotely read and write the microcontroller sensors/actuators. In the case of Achille’s MoT, the makers create the RESTful methods using *Node-RED* [JS\_Foundation 2016] deployed on an IBM Blue Mix account. Node-RED programming is performed through

a visual, graph-based, notation. For example, some methods are:

1. <http://www.usedwebserver.com/TurnLEDs?onOff=status&RGB=rgbcode>
2. <http://www.usedwebserver.com/getRFIDcardValue>
3. <http://www.usedwebserver.com/getGPSPosition>

The first one is a POST method used to switch on/off the MoT LEDs. The second one is a GET method used to retrieve the value of the read RFID card. The third one is a GET method used to retrieve the coordinates of the MoT.

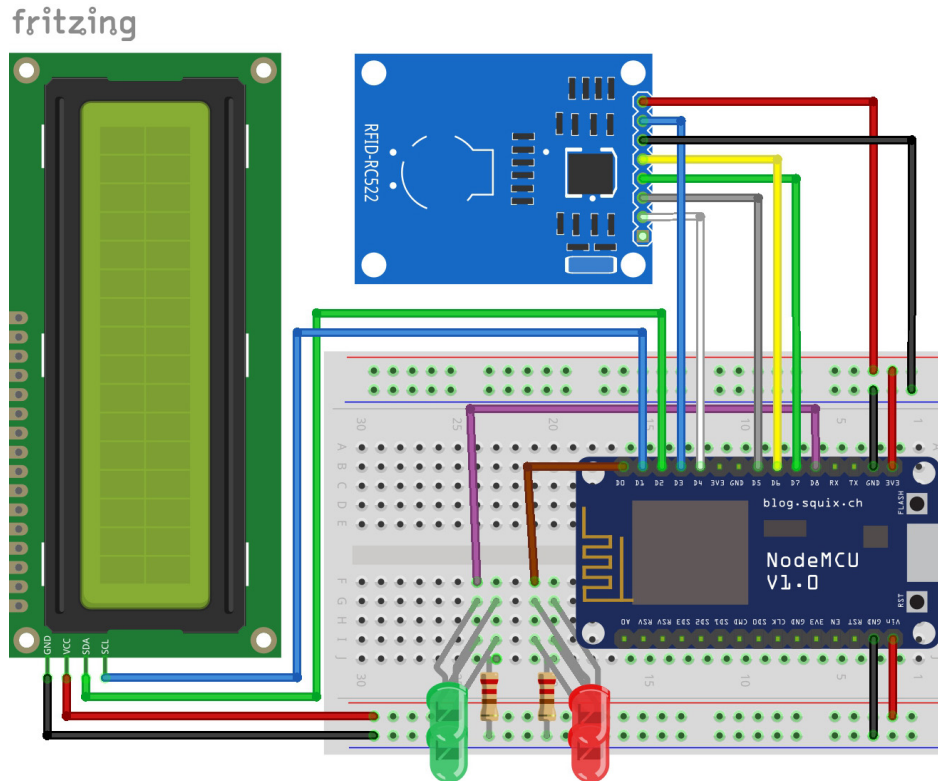


Figure 5. Electric schema of the Mouth of the Truth used by the guide

## 5.2. Programming the Game Engine Web service

In order to create the smart visit experience, Achille also needs managing the points that the teams win/lose during the game. To this aim, he asks to an IT expert to develop a solution that fits his needs. Thus, the IT expert creates a MongoDB database to store the team points and builds on it a Web service by using Node-RED. This Web service exposes some RESTful methods that, once registered in EFESTO-4SE, will be used in the ECA rules definition. For example, some methods are:

1. <http://www.usedwebserver.com/AssignPointToTeam?point=pointsToBeAssigned&team=targetTeam>
2. <http://www.usedwebserver.com/getPoints?team=targetTeam>

3. <http://www.usedwebserver.com/winningTeam>
4. <http://www.usedwebserver.com/StartNewGame>

The first one is a POST method used to assign points (*pointsToBeAssigned* variable) to a specific team (*targetTeam* variable). The second one is a GET method used to retrieve the current number of points of a team (*targetTeam* variable). The third one is a GET method used to retrieve the team with the highest score. The last one is a method to be invoked every time Achille starts a new game, so that all the old data are deleted.

### 5.3. Registering smart objects and services in EFESTO-4SE

After the creation of the smart objects and Web services needed for the customization of EFESTO-4SE, according to the middle-layer activities of our meta-design model, professional developers and domain experts collaborate to customize the general-purpose platform by registering and configuring specific resources. In the Achille's scenario, the platform customization mainly consists in registering the MoT smart object and the Game Engine Web service.

In order to register such resources in EFESTO-4SE, an administration panel in EFESTO-4SE supports professional developers to register new resources by indicating, in a form-based page, all the information useful to invoke the resource methods. For example, the expert has to indicate information like name, description, authentication type (OAuth, OAuth 2.0), base URI, list of methods and their type (e.g., GET, POST). According to the registered methods, in EFESTO-4SE the events are related to the GET methods while the actions are related to the POST/DELETE/UPDATE methods. When all the resource information are provided, a JSON file is created as summary of the resource information, stored in the platform and connected to the user account.

In addition, starting from the registered events and actions, the professional developers can refine their behavior according to the requirements expressed by domain experts. For example, in the MoT there is a POST method to turn ON/OFF the RGB LED, which is registered as action to turn on and off the specified LED (<http://www.usedwebserver.com/TurnLEDs?onOff=status&&RGB=rgbcode>). However, the actions that Achille wants to obtain on the MoT are 1) *Blink eyes green for N Second* and 2) *Blink eyes red for N Second*. Thus, according to the Achille request, the professional developers use the EFESTO-4SE administration panel to adapt the original action by creating a JavaScript wrapper. For example, the desired action *Blink eyes green for N Second* is created by defining a new JavaScript function that invokes the LED method to blink green the LED for N seconds.

### 5.4. Using EFESTO-4SE to design the Smart Experience

The EFESTO-4SE prototype was developed as a Web application using 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).

In the following, by focusing on the characterizing aspects of the approach and the model, i.e., the definition of smart object custom attributes and the creation of ECA rules, EFESTO-4SE usage is illustrated by describing how Achille would create the serious game to be played at the archaeological park.

#### 5.4.1. Defining Smart objects custom attributes

In EFESTO-4SE, we introduce novel visual mechanisms through which the designer of the smart experience can make sense of the capabilities offered by the technology infrastructure. The proposed visual paradigm is grounded on the Transformative User Experience (TUX) principles [Latzina and Beringer 2012] we recently implemented in a mashup platform [Ardito et al. 2015b] where the idea was 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-4SE 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 can visually move smart object instances inside the VACs according to the semantics they want to assign. In our current version of EFESTO-4SE we developed three VACs, i.e., the *Location*, *Categories* and *Associations* containers. The first container is a widget showing a Google Maps and allowing users to associate coordinates' values to smart objects. The second container represents an attribute with a set of pre-defined values; the users can add/remove a set of columns, one for each attribute value. The last container represents an attribute with an unpredictable set of values; it is shown as a couple of columns, the first one to collect the smart objects, the second one to associate a specific value to a smart object. All the VACs can be renamed in order to establish the user-defined name of the custom attribute.

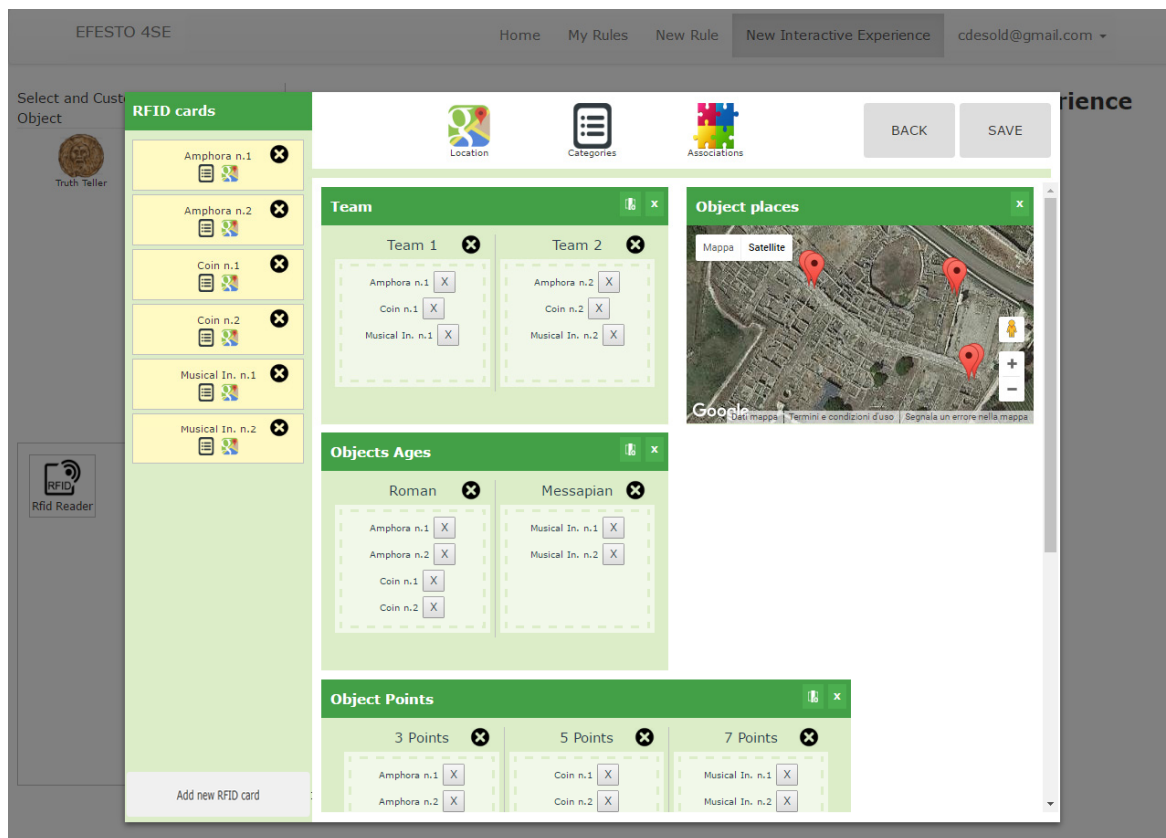


Figure 6. Defining objects and their attributes for the scenario “game in the archaeological park”

In the example shown in Figure 6, Achille has already logged in EFESTO-4SE and has selected “New Interactive Experience”. In the workspace he sees the list of objects types that he previously configured with the help of professional developers of EFESTO-4SE. He thus selects the RFID card object, by clicking on the corresponding icon, and starts defining how many cards are needed and which are the custom attributes that can allow him to define the smart experience. In Figure 6, Achille has already added 6 cards and given them a name (e.g., Amphora n.1, Coin n.1, etc.). Through the VACs included in the right-hand area of the workspace, he then defines the custom attributes. Each VAC corresponds to a custom attribute. In particular, Achille has used three “Categories” VACs, which associate some categorical terms to the smart objects they include. Achille named one VAC “Team”, he added two columns - Team 1 or Team 2 – to specify possible values, and dragged in them the objects to be assigned to Team 1 or Team 2, respectively. Thus, those cards have been annotated with the “Team” custom attribute and the corresponding values. Achille did the same for assigning, to every objects, the “Age” custom attribute – with values “Roman” and “Messapian” – and the “Points” – “3”, “5” and “7”. One container called “Location” is used to assign GPS coordinates to an object as sensible locations by positioning it on a map.

#### 5.4.2. Creating ECA rules

Once the smart objects have been characterized by their custom attributes, Achille defines their behavior by defining Event-Condition-Actions (ECA) rules [Pane et al. 2001]. In our previous work, we proposed a composition paradigm that supports users without technical skills in computer programming to define ECA rules [Desolda et al. 2017a]. The design of such paradigm has been driven by the 5W model, typically adopted in journalism to analyze the complete story about a fact by answering to the 5 questions: 1) Who did it? 2) What happened? 3) When did it take place? 4) Where did it take place? 5) Why did it happen? These five questions were used during an elicitation study to guide participants in proposing user interfaces and interaction techniques for the creation of ECA rules. The design phase resulted in three different user interfaces and interaction paradigms that we then compared during a controlled experiment. The most promising prototype was the one we called EFESTO-5Ws. Additional information about such studies are reported in [Desolda et al. 2017a].

While using the composition paradigm implemented in EFESTO-5Ws, Achille will see also the list of custom attributes he defined for the smart objects and will be thus enabled to use them for the definition of ECA rules. In particular, custom attributes can be used 1) as variable within conditions constraining the rule activation and 2) as parameters in the rule events/actions. In the considered example, Achille could create a rule like:

```
IF MoT.RFID card Read AND
    MoT.Position reached is equal to RFID card Discovery Place
THEN MoT.Blink eyes green for N Second AND
    GameEngine.AssignPointToTeam(RFID card.Points, RFID card.Team)
```

This rule exploits custom attributes as event conditions and as action parameters. For example, the branch “*MoT : GPS position* is equal to *RFID card Discovery Place*” is true if the MoT GPS position is equal to the Discovery Place attribute value specified for the read RFID card. The action branch, instead, refers to the Web service that manages the team points. In this case, a service method assigns the points of the read card to the team of the read card. This is an example of the use of custom attributes as action parameter.

In order to define the previous rule, Achille enters the rule creation page in EFESTO-4ES, by clicking on the “New Rule” menu item. Then he clicks the “+Event” button (Figure 7, circle 1) and a wizard procedure



allows him to select the *MoT* and the *RFID card read* event, thus creating the first rule event (Figure 7, circle 2). To define the second condition that triggers the rule, he clicks again the “+Event”, selects the *MoT* and the *Position reached* event and specifies as event parameter the *Discovery Place* of the read RFID card (Figure 7, circle 3).

After defining the events, Achille creates the actions that are executed when the event conditions are satisfied. Achille clicks on the “+ Action” button (Figure 7, circle 4) and chooses the *Mouth of Truth*, selects the *Blink eyes green for N Second* action to be activated and specifies, as action parameter, the number of seconds the led have to blink (Figure 7, circle 6). Afterwards, he adds another action by selecting the service *GameEngine* and the *Assign Point To Team* action specifying, as action parameters, the number of points (parametrized with the *RFID\_card Points* attribute) and the team (parametrized with the *RFID\_card Team* attribute), thus creating the second action (Figure 7, circle 7). At the end, the rule is saved by clicking on the “Save” button at the bottom of Figure 7. 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.

Advanced features not used in this example support the creation of rules with spatial and time constraints on events and actions [Desolda et al. 2017a], as well as to combine events and actions with complex logical expressions [Desolda et al. 2017c].

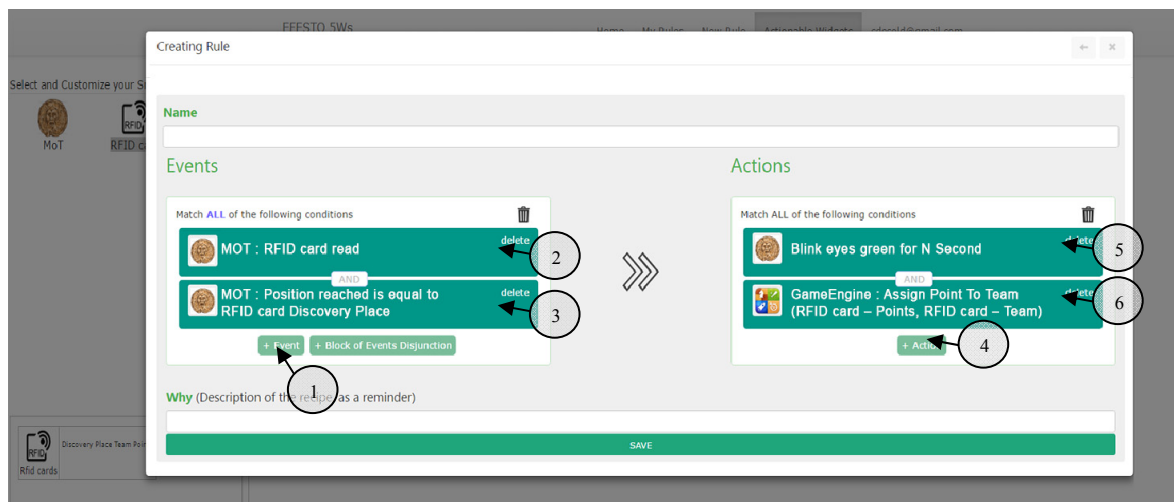


Figure 7. Example of ECA rule created for the scenario “game in the archaeological park”

## 6. Formative Evaluation with Cultural Heritage Guides

A formative evaluation of the EFESTO-4SE 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 4 professional cultural-heritage guides who were asked to use EFESTO-4SE to create an interactive experience according to a given scenario. In this study the goal was the assessment of the composition paradigm implemented in EFESTO-4SE w.r.t. the CH guides’ mental model.

### 6.1. Participants and Design

We recruited 4 participants (3 female) among the 6 who participated in the elicitation study (see



Section 3). They aged between 29 and 38 ( $\bar{x} = 33.5$ ,  $SD = 3.87$ ). Specifically, 3 of the 4 professional guides of the WWF wildlife park of Torre Guaceto (Italy) who were involved in the elicitation study, and 1 professional guide operating in different natural science museums in Italy. Various reasons persuaded us to involve the same subjects (at least the 4 out of 6 who were available). In particular, in the elicitation study they already followed the process of creating a smart experience, starting from reasoning on narrative, smart objects, semantics and rule. In this study they could move forward to the last step, i.e., the actual definition of the smart experience by means of EFESTO-4SE. This should also help the participants not being disoriented by their role of active creators of their tools. This is a problem that often affects the results reliability, as we observed in previous studies in which we evaluated EUD tools [Ardito et al. 2014a].

The participants were asked to use EFESTO-4SE in order to create the smart visit experience described in a scenario very similar to the game designed by the archaeological park guide (see Section 3.4). Summarizing the scenario, visitors are divided in teams and provided with a deck of smart cards, while Achille, i.e. the guide, has a Mouth of Truth (MoT) device reading the cards and providing a feedback about answer correctness. The scenario was slightly adapted to the guides' specificity. For example, in the case of the WWF guides, Achille was a guide of the wildlife park and the smart cards depicted flora and fauna pictures of the Torre Guaceto oasis.

At the end of the scenario narrative, the following tasks guiding the participants' interaction with EFESTO-4SE were administered:

- Read accurately the scenario;
- Identify the smart objects you need, e.g., smart cards and devices;
- Assign to each object the custom attributes for characterizing their semantics in the scenario;
- Create the rules for defining the behavior of the objects.

An online questionnaire to evaluate user satisfaction was eventually administered.

## 6.2. Procedure

The entire study took place in a quiet and isolated room at the Computer Science Department of University of Bari Aldo Moro, where we installed the study apparatus (a laptop connected to an external 19-inch large monitor and a web camera). 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 (see Figure 8).

The guides participated individually and underwent the same procedure, which lasted about 1 hour. First, the participants were asked to sign a consent form. Then, the facilitator showed a quick introduction about the use of EFESTO-4SE. Then, they were provided with a sheet reporting the scenario and the list of tasks. They were also provided with the MoT smart object and two card decks that they could use to verify the interactive experience under creation. Afterwards, they started the creation of their interactive experience. During the interaction with the platform prototype, they were asked to verbalize their thoughts and comments according to the think-aloud protocol. At the end, participants filled in the online questionnaire.

## 6.3. Data Collection & Analysis

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. Online questionnaires were filled in during the study.

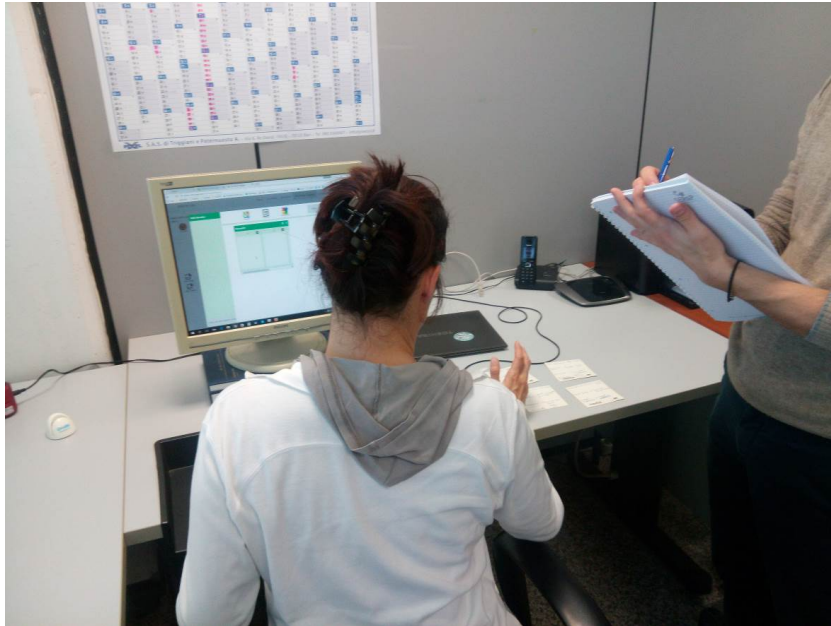


Figure 8. A participant and the facilitator during the formative evaluation.

The two researchers transcribed their notes, which were extended by video and audio analysis. Some 70% of this material was independently double-checked by the two researchers. The initial reliability value was 85%, thus the researchers discussed the differences and reached a full agreement. The transcripts were analyzed by thematic analysis following a semantic approach. Themes were identified within the explicit or surface meaning of the data [Braun and Clarke 2006a].

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 measure the loyalty that exists between a provider and a consumer. The NPS question asks the users to rate, on a scale between 0 and 10, how likely they 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  $\geq 9$ ) and detractors (users who scored the system  $\leq 6$ ). 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-4SE usability and learnability. The last 12 questions were introduced to deeply evaluate the main features of EFESTO-4SE, i.e., 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 features [Hart and Staveland 1988].

#### 6.4. Results

The main results come from the questionnaire. The first indication was obtained by the NPS score that is equal to 75, i.e., excellent. Despite the limited number of participants, the final NPS score appears promising because it indicates an attitude towards suggesting this system to other CH guides.

The NPS result has been 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 70.0/100 (SD = 15.4), which is in line with 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 a good 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 59.4 (SD = 27.7), while the *System Usability* score was 72.7 (SD = 12.6). Thanks to the analysis of the notes and video recordings, we can mainly attribute the lower learnability score to the difficulties that participants experienced with the creation of custom attributes.

To deeply investigate the usability of EFESTO-4SE with respect to its two main features, i.e., the custom attributes creation and the ECA 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 = 3/10, rule definition = 2.25/10), indicating that participants did not feel frustrated while creating CAs or ECA rules. Regarding the *effort*, we can see that the *General Effort* obtained a high negative score (attribute creation = 6/10, rule definition = 5.25/10) suggesting that participants have to put some effort in performing the tasks' scenario. Looking to the *Mental Effort* and *Physical Effort*, we can attribute the previous score to a high mental effort (attribute creation = 5.25/10, rule definition = 4.75/10), while physical effort was quite low (attribute creation = 2.25/10, rule definition = 3.25/10). The *Performance* obtained a high positive value in both the dimensions (attribute creation = 7.25/10, rule definition = 7.25/10), indicating a high satisfaction in using the system.

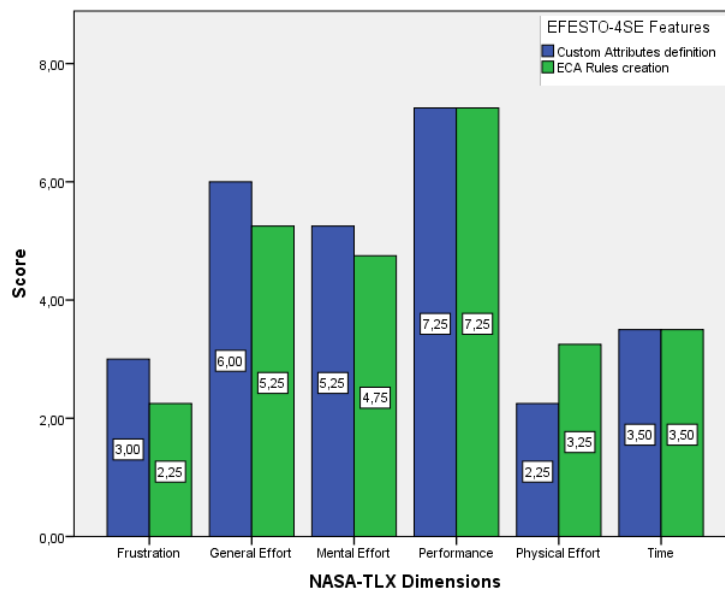


Figure 9. NASA TLX dimensions related to the custom attributes definition and ECA rule creation.

### 6.5. Discussion and design implications

The formative study allowed us to collect important indications about some usability issues to be addressed. In the following, we summarize the main findings of the studies and discuss some design implications.

**Constraining the flow of configuration and design activities.** EFESTO-4SE supports the creation of smart experiences by asking users to take part to different phases like: smart objects initial configuration, creation of custom attributes and their association with smart objects, and creation of ECA rules determining their behaviors. One evident problem observed during the study regards the management of all these phases: two participants, indeed, reported that EFESTO-4SE should be more effective in guiding users in the overall process. Actually, the definition of CAs and ECA rules occur into two separated windows and this distinction confused the participants, who had to switch among them during the smart-experience creation. Even if the access to these two windows are rooted to a home page where users can select “CA creation” or “ECA rules definition”, they 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 term of smart objects, CA and ECA rules. According to these problems and participants’ suggestions, we believe that systems enabling the creation of smart experiences have 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.

**Providing adequate representations for custom attributes.** As explained in Section 3, the composition paradigm we implemented for the creation of CAs is inspired by some TUX principles [Beringer and Latzina 2015] that we adopted in our previous work [Ardito et al. 2015b]. It indeed consists of visual containers inside which users can move smart objects to associate them with the CA containers. As emerged by triangulating questionnaire results with users’ comments, CA definition resulted more difficult than ECA rules creation. Indeed, the low SUS learnability score demonstrated that users encounter some difficulties in learning EFESTO-4SE. The NASA-TLX scores then helped us identify the CA creation phase (for which the *general effort* and *mental effort* were higher) as responsible of the low SUS learnability score. The NASA-TLX results were also confirmed by the analysis of the externalized comments. For example, half of the participants did not autonomously understand how to create the annotation containers and asked facilitators for help. No significant problems were observed when the participants created ECA rules. It is worth mentioning, however, that the ECA rule paradigm is more mature thanks to the previous studies performed to elicit and evaluate it [Desolda et al. 2017a]. One of the participants suggested a spreadsheet-based solution to create CAs: according to this suggestion, a spreadsheet visualization can assist the user, who could use a table in which he/she allocate the objects in the rows, the attributes in the columns, and assign the attribute value in the cells. Since the definition of custom attributes is a crucial point in the overall creation of smart experiences, the emerged problems suggest that improvements have to be identified for the proposed visual paradigm. Even different metaphors, like the one based on spreadsheets, have to be designed and investigated.

**Adopting Meta-design to identify proper domain-specific abstractions hiding technical details.** Participants sometimes did not immediately understand how to create annotation containers; also they were not able to identify immediately what the different containers were meant for. For example, we developed two general-purpose containers called “category” and “association”, the first one to create a custom attribute with a pre-defined set of values, the second one to create a custom attribute with an unpredictable set of values. However, they encountered some difficulties to distinguish between these two roles. For example, one user said: “To create the Point attribute, I can use both the category and association containers. Which of them I

have to use?”. In line with the meta-design approach we used to customize EFESTO-4SE, another customization activity can consist in pre-configuring the annotation containers to avoid unnecessary complexity, for example to adopt an adequate terminology that the end users can master.

## 7. Conclusion

This article presents 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 Internet of Things, to respond to the specific need of exploiting IoT to mediate narrative and learning goals for the CH content appropriation. 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 experiences. The goal was to support the composition of smart objects that also need to be contextualized with respect to some content to be passed to the smart experience participants. The conducted study has shown 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 a running prototype and preliminarily validated it.

Smart objects are very often conceived as devices able to sense or to produce low-level signals. With this article, we aim to promote a new perspective that extends the semantics of smart objects by means of properties that a smart-experience designer deems useful for a specific context. Considering smart objects as mere producers/consumers of signals is indeed limiting when non-programmers need to design articulated smart experiences where smart object behavior needs to be put in some context. Thanks to the studies that we conducted, we realized that this limitation arises when IoT has to support engaging visit experiences to CH sites; but there are also other domains where this need is evident. One is for example e-health, where smart objects are exploited in therapy scenarios characterized by some learning goals [Garzotto et al. 2016]. We therefore believe that that this work, and especially the abstractions that we identified for modeling smart objects and smart experiences, can be beneficial in all those situations where the addition of semantics on top of smart objects would facilitate the definition of smart experiences by people who don't have attitude towards programming.

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 enabling end users to define 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 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.

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 formative 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 on rule activation. This is an aspect that we did not investigate 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.

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