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An experimental study to validate Smart Interactive Experience designing tools

ABSTRACT

Smart Interactive Experiences (SIEs) are usage situations created by synchronizing the behavior of multiple smart devices. In order to allow SIE design by domain experts who do not necessarily have skills in computer programming, three paradigms have been designed, two based on Tangible User Interfaces and one on Augmented Reality. These paradigms aim to enable domain experts to enrich SIE resources (e.g., smart devices) with semantic properties referring to their domain knowledge and expressing domain-specific operational meanings. The aim of the enrichment is to facilitate the definition of trigger-action rules governing the SIE dynamics. A comparative within-subject study was set up to unpack and better understand the contribution of each design paradigm to the creative processes of SIE design. This document describes the performed study.

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System Comparison

SIE design is a process characterized by two central phases, i.e., the creation of custom attributes and the definition of ECA rules. Since we already assessed the validity of the ECA rule creation paradigm (Desolda et al., 2017), we isolated the only variable not yet evaluated that could impact on the process, i.e., the custom attributes creation phase. To this aim, we carried out an experimental study to understand how the proposed systems support non-technical users in the custom attribute definition. To cover the entire process, and verify whether the custom attribute definition would support the designers in the SIE conception and in the following design activities focusing on the SIE dynamics, we also asked the participants to write down the ECA rules on a paper sheet, according to the schemas of rules supported by our system (Desolda et al., 2017). As ground for this experiment, we chose the Cultural Heritage (CH) domain due to the recent and growing interest of guides and curators in the adoption of smart objects as artifacts integrated into museums and CH sites to support the fruition of content (Petrelli and Lechner, 2014; Zancanaro et al., 2015).

The research questions driving the study are:

*RQ1:* Do the three systems support the creative design of custom attributes?

*RQ2*: Which elements of each system affect the creative design of custom attributes?

Participants and Study Design

We recruited a total of 18 students attending the master's degree course in CH (13 females, mean age 23.9 years, SD = 6.64, min = 20, max = 44). Participants were randomly organized in nine groups of two. Their participation was recognized as part of their curriculum activities and rewarded with additional credits. As resulting from the demographic questionnaire they filled in during the study, 10 of them already attended at least one excavation campaign (x̅  = 1.1, SD = 0.99, min = 0, max = 3), spending a good amount of days in those kind of professional activities (days x̅ = 17, SD = 16.02, min = 0, max = 45). Five of them also organized guided tours in museums or in archaeological parks.

The participants knew each other well because they attended the same university courses, which usually include a few students (about 20 people) or were used to participate in the same professional and social activities.

Participants had a moderate experience in IT (x̅ = 4.8, SD = 1.86, min = 1, max = 8) and in using mobile devices (x̅ = 6.4, SD = 1.65, min = 3, max = 9), interactive displays (x̅ = 5.3, SD = 1.93, min = 2, max=9) and smart objects (x̅ = 4.2, SD = 2.10, min = 1, max=9). Likert scale ranging from 1 to 10 (1 very low - 10veryhigh) were used to assess such skills. We performed a controlled experiment adopting a within-subject design, with the *system* as an independent variable and three within-subject levels, i.e., *Tangible*, *Explorative, Tactile*.

Procedure

The study was organized in 3 main phases and every group followed the same procedure. Initially, each group elaborated an idea of SIE without using technology support (first phase). Then, they proceeded with the detailed design of the initially conceived SIE by using the three systems, one at a time (second phase). Finally, the groups participated in a focus group (third phase). All 9 groups got the same design brief. A pilot study involving further three groups was previously performed to evaluate the system reliability and the research methodology (e.g., time constraints, coding techniques, video-recording activities).

The study took place in three quiet university rooms that were arranged to create an environment familiar to CH experts: we identically set-up these rooms by placing on desks and shelves significant books, objects, pictures of excavation campaigns tagged with QR codes, and other material typical of CH expert office. In addition, in each of these three rooms, we installed the apparatus for each system.

Three HCI experts were involved during the three phases: one acted in the first phase; the other two acted in the second phase for each group, one as a facilitator and the other as an observer. The comparative study lasted three days. Six participants, in groups of two, were observed each day. All the three experts moderated the focus group at the end of each day.

* + 1. First phase: SIE conception

The HCI expert introduced the participants to the study purpose and asked them to sign a consent form. Nobody refused to participate in the study. Then they were asked to fill in the demographic questionnaire to collect participants’ information.

After, the participants were provided with a two-page booklet. The first page reported a scenario they had to read to understand what SIEs are and how a CH expert can design them by identifying the smart objects and their custom attributes, and by defining ECA rules. The second page reported a design brief each group had to follow to figure out an idea of SIE.

The driving scenario was designed together with three CH experts, not involved in the study, with the aim to guide the participants in elaborating ideas in a context they know but that is general enough to let them feel comfortable without constraining their ideas. The scenario included details (e.g., the smart objects to be adopted) to help them shape up their thoughts. The participants were thus asked to act as curators of a museum installed at the Department of Humanities in our university. They had to arrange a new exhibition called “How do CH experts work?” to disseminate the scientific value of the archaeological investigation. In particular, they were asked to define an interactive visit focusing on the stratigraphic investigation exposing the involved tools and multimedia material. To create this visit, CH experts would use objects like a book reporting clues to identify the excavation site, aero-reconnaissance photos of potential excavation sites, several digging tools (e.g., trowel, north arrow, meter), videos illustrating the archaeologists’ work available on DVDs. Such objects could be conceived by the participants as smart as they preferred, for example by attaching RFID tags so that they can be detected by reader devices.

After reading the scenario and discussing with the facilitator what SIEs are, the group started to figure out their ideas. In order to facilitate this activity, brainstorming was introduced as a means to promote the generation of ideas before their implementation (Lamm and Trommsdorff, 1973). Inspired by (Burnam-Fink, 2015; Kohno and Johnson, 2011; Kudrowitz and Wallace, 2013), the brainstorming was organized in different steps. This approach was loosely inspired by the 6-8-5 sketching concept (Unger and Chandler, 2012), where participants were challenged to create 6-8 concepts within a timeframe. First, acting separately, each of the two group members took 5 minutes to propose 3-4 rough ideas of SIE. Then, each member was given 3 minutes to illustrate the ideas to his/her partner. In the end, the partner had 2 minutes to provide some feedback. Afterward, acting again separately, in 10 minutes they refined their ideas thanks to the partner’s feedback. Finally, they had 20 minutes to discuss together the new ideas in order to select the best one or to create a new one by merging some of their ideas. During this step, they used a flipchart to sketch their ideas. The final idea, with indications of possible smart objects, custom attributes and smart-object behavior, was transcribed on a blank sheet. The entire phase lasted about one hour for every group.

* + 1. Second phase: SIE detailed design

Starting from the generated idea of SIE, every group designed it in detail by using each of the three systems. To avoid carry-over effect, the systems ordering was counterbalanced according to a Latin Square design.

The facilitator introduced the first paradigm and demonstrated its usage by showing examples of custom attributes creation. The demonstration did not involve smart objects and examples used in the leading scenario. To complete the training, the participants were invited to specify some custom attributes, with the possibility to ask the facilitator for help. This phase lasted about 5 minutes.

After the training, the group started to define the custom attributes proposed during the previous phase; in some cases, they introduced further attributes they conceived during the system usage. Then, they had to use such custom attributes to define ECA rules governing the smart-object behavior. To simplify and speed-up the ECA rule creation, which is out of the scope of this study and was already assessed in previous experiments (Desolda et al., 2017), the participants were asked to write down the ECA rules on a paper sheet, where empty schemas of rules were reported. This phase lasted 15 minutes. In the end, they filled in an online questionnaire about the system they used. Before repeating the same procedure with the next system, the group was invited to relax for 5 minutes.

A paper questionnaire was administered at the end of the second phase to compare the user satisfaction with the three systems. The total time of the second phase was about 90 minutes. Since the first phase was conducted by a different HCI expert (the instructor), we could manage to have two groups at a time working almost in parallel.

* + 1. Third phase: discussion during focus groups

Each day of the study, once all the three groups completed the second phase, they attended together a focus group. The discussion revolved around a list of topics like the experience in using the systems, in working in group, in creating SIEs with the proposed systems.

Data Collection

Different types of data, both quantitative and qualitative, were collected. We considered: *i)* the reports of the SIEs that the participants created during the first conception phase, *ii)* the notes taken by the observer on significant behaviors or externalized comments of the participants during the three phases, iii) the answers to the questionnaires that the participants filled in during the study.

In the different phases, all the interactions and focus group discussion were audio-video recorded by using a camera. Two researchers transcribed the observer’s notes, the questionnaire open questions, and the discussions of the focus groups. They also analyzed and wrote out some useful parts of the audio-video recordings. A thematic analysis was carried out on these data (Braun and Clarke, 2006). Then, the two researchers independently double-checked the results. The initial reliability value was 75%, thus the researchers discussed the differences and reached a full agreement.

The participants were asked to fill in a questionnaire including general demographics plus IT skills, particularly focused on our prototype technologies: smartphones, smart objects and interactive displays, as already reported in Section 4.1.

A second questionnaire, organized in 2 sections, was used to evaluate each system during the second phase. The first section included the Creativity Support Index (CSI), a psychometric survey to evaluate the ability of a tool in supporting users engaged in creative works (Cherry and Latulipe, 2014). The CSI measures six dimensions of creativity support: *Exploration*, *Expressiveness*, *Immersion*, *Enjoyment*, *Satisfaction with* *Effort* (*Effort* for short in the following*)*, and *Collaboration*. It helps understand not only how well a tool supports creative work overall, but also which aspects of creativity support may need attention. The second section had two open questions about what participants liked and disliked about the system.

The third questionnaire, administered at the end of the second phase, asked the participants to rank the three systems based on their usefulness, completeness and ease of use (from 1 to 3, 1 is the best), and to vote for the best system.

In this study no traditional metric, such as time or success rate, was considered for the following reasons. As said above, the objective of the study was to verify if and how the three systems support the creative design of custom attributes and time is not an appropriate measurement, on the contrary hasty activities can damage the creativity as pointed out by (Oppezzo and Schwartz, 2014). We could not take into account the success rate, because the participants were not asked to perform a defined set of specific tasks, but we asked them to create a SIE, which each couple has defined, changed and modeled independently and personally.

One-way repeated measures ANOVAs (all Greenhouse–Geisser corrected) with posthoc pairwise comparisons (Bonferroni corrected) were adopted to analyze CSI results and the number of smart objects and custom attributes involved in the created SIE. Friedman test was adopted to analyze differences in systems ranking and CSI dimensions, with Wilcoxon signed-rank test used as posthoc pairwise comparisons. A p-value <0.05 was considered statistically significant.

Results and discussion

* + 1. Support to Custom Attribute definition

The three systems obtained a CSI score close to 80/100, which means very good support for the creative definition of custom attributes (*Explorative* x̅ = 80.25, SD = 11.56; *Tangible* x̅ = 78.79, SD = 13.55; *Tactile*x̅ = 78.25, SD = 13.47), without significant differences (*F*(1.994, 33.901) = .178, *p* = .837, partial η2 = .010). This positive result confirms the validity of the aspects introduced in the three systems to stimulate the designers’ creativity in the identification of custom attributes.

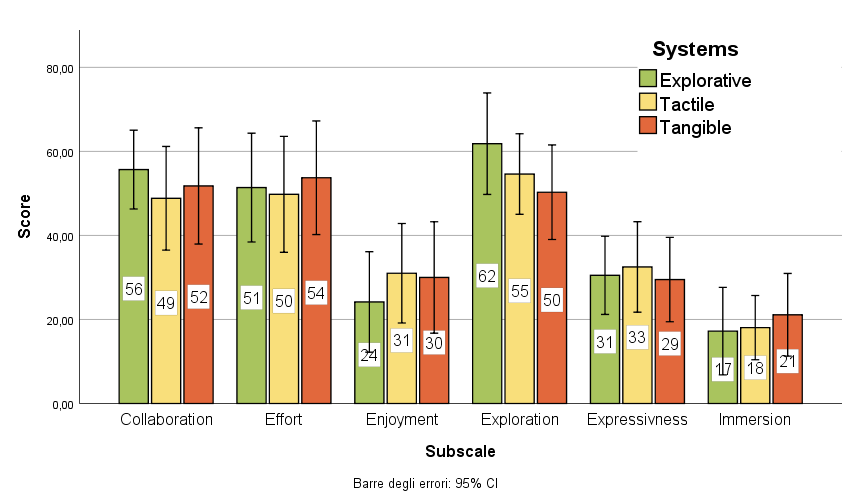


Figure 1. Scores for each CSI dimension. Higher score is better.   
Error bars 95% confidence interval.

We also analyzed each system separately looking for differences among the CSI dimensions. For the *Explorative* system, significant differences emerged (χ2(5) = 33.424, p = 0.000). Collaboration was higher than Enjoyment (Z = -2.936, p = 0.003), Expressiveness (Z = -2.961, p = 0.003), and Immersion (Z = -3.245, p = 0.001). Effort was higher than Enjoyment (Z = -2.678, p = 0.007), Expressiveness (Z = -2.069, p = 0.039), Immersion (Z = -2.817, p = 0.005). Exploration was higher than Enjoyment (Z = -3.202, p = 0.001), Expressiveness (Z = -3.158, p = 0.002) and Immersion (Z = -3.245, p = 0.001). Finally, Expressiveness was higher than Immersion (Z = -2.047, p = 0.041). This result showed that the dimensions that mainly contribute to increase the overall CSI score of the *Explorative* system were Collaboration, Exploration and Effort. Concerning the Collaboration and Exploration dimensions, we derive that this system allowed the participants to work together easily, and it facilitated them in sharing ideas and design alternatives. This result can be quite surprising because mobile phones are typically more prone to single-user interaction. We believe that the exploration of the surrounding environment of the two CH experts with the common goal to identify objects to create an engaging SIE for the museum visitors is highly stimulating and thus, we can assume that the configuration of the *Explorative* system does not limit collaboration, on the contrary it tends to stimulate it. Similarly, in relation with the Effort items, we can state that the participants felt satisfied with the effort they put to create custom attributes. A possible explanation is that designers mainly created attributes by reusing properties of the source objects, thus lowering the effort to think and create custom attributes from scratch.

For the *Tactile* system some differences emerged (χ2(5) = 24.280, p = 0.000). Collaboration was higher than Immersion (Z = -3.028, p = 0.002). Effort was better than Enjoyment (Z = -2.156, p = 0.031) and Immersion (Z = 2.897, p = 0.004). Exploration was better than Enjoyment (Z = -2.679, p = 0.007), Expressiveness (Z = -2.680, p = 0.007) and Immersion (Z = -3.480, p = 0.001). Enjoyment was better than Immersion (Z = -1.960, p = 0.050). Thus, Collaboration, Effort and Exploration dimensions primarily contribute to increase the overall CSI score. The positive Collaboration score is mainly given by the nature of the tabletop system, which natively fosters intuitive social interaction and collaboration (Catala et al., 2012). An interesting result comes from the Effort: despite the mixed use of tactile interaction and TUI could generate a higher effort, participants felt satisfied with the SIEs they designed and with the effort put to produce them. Regarding the positive Exploration score, the inspection of its items highlighted that it was easy for the participants to explore many different ideas and design options, and the system was helpful in allowing them to track different ideas.

Also, for the *Tangible* system some differences exist among CSI dimensions (χ2(5) = 18.974, p = 0.002). Collaboration was higher than Enjoyment (Z = -2.091, p = 0.037), Expressiveness (Z = -2.178, p = 0.029), Immersion (Z = -2.679, p = 0.007). Effort was higher than Enjoyment (Z = -2.156, p = 0.031), Expressiveness (Z = -2.331, p = 0.020), Immersion (Z = -3.071, p = 0.002). Finally, Exploration was better than Expressiveness (Z = -2.770, p = 0.006), Immersion (Z = -2.896, p = 0.004) and Enjoyment (Z = -2.287, p = 0.022). As for the previous two systems, Collaboration, Effortand Exploration dimensions contribute to increase the CSI score. For the Collaboration dimension, a possible explanation is that the use of tangible attributes and post-it notes supported the participants to design together SIEs, also sharing easily their ideas emerged during the design process, thus determining a positive Collaboration score. Similarly, also for the satisfaction with Effort,the simplicity of the use of post-it notes and tangible attributes made the participants feel gratified by the result and the effort put on it. A possible explanation of the positive *Exploration* score is that users of the *Tangible* system can collaboratively elaborate different ideas quickly, thanks to the opportunity to write attributes name and values on disposable post-it notes, thus simplifying and speeding-up the exploration and discussion of different ideas.

Besides measuring the subjective perceived support to creativity, inspired by (Oppezzo and Schwartz, 2014) we introduced two objective variables as indicators for creativity of a SIE design process: *i)* the number of useful custom attributes and *ii)* the number of useful smart objects. In both cases, “useful” refers to those attributes and ECA rules that the participants included in their final SIE. Almost 10% of CAs and ECA rules conceived during the ideation phases were not used in the final SIEs while almost 30% of new custom attributes and smart objects were introduced in the SIEs during the use of the systems. However, the number of custom attributes created by using the three systems (*Explorative* x̅ = 6.88 SD = 3.78, *Tactile* x̅ = 4.22 SD = 1.98, *Tangible* x̅ = 4.55 SD = 1.66) is not statistically different (*F*(1.277, 91.333) = 3.328, *p =* .094, partial η2 = .294), as well as the number of smart objects included in the SIEs while using the three systems (*Explorative* x̅ = 3.22 SD = 1.86, *Tactile* x̅ = 2.55 SD = .73, *Tangible* x̅ = 2.55 SD = .73) without significant differences (*F*(1.181, 9.449) = 1.067, *p* = .342, partialη2=.118).

A Pearson product-moment correlation was used to determine, for each system, the relationship between CSI score and both the number of custom attributes and the number of smart objects involved in the SIEs. A significant positive correlation emerged only for the *Tangible* system between the CSI score and number of smart objects (r = .394, *p =* .05). This result shows that the participants felt that their creativity was stimulated when they included a high number of smart objects and, consequently, it was not sufficiently stimulated when they included few smart objects. Even if this can seem a trivial result, this aspect deserves more attention because this correlation emerged only with the Tangible paradigm, even if with the other systems, and in particular with the *Explorative* system, the participants also included a good number of smart objects in the defined SIEs. By considering our observations and the focus group results, a possible and reasonable explanation is to be found in the SIE-overview modalities offered by the different systems. In fact, in the Explorative paradigm, in order to access the overview of the smart objects and their custom attributes, participants had to switch from the exploration window to a new window showing the list of smart objects and their attributes. This caused a loose of time and some difficulties that compromised the participants’ awareness and perception on the SIE they were creating. In the *Tactile* system, on the other hand, the overview on SIE definition is easily accessible because on the tabletop the designer can see the spatial composition of the different smart objects; however, it is also constrained by the physical space offered by the tabletop, which limits the number of smart objects and attributes that can be placed on it at the same time. This in a sense forces the designers to define custom attributes for a limited number of smart objects. The *Tangible* system, instead, provides an excellent overview: the desktop where the SIE is created does not have the limits posed by the other systems, thus designers can compose a larger number of smart objects still being able to access the SIE overview. This increases the awareness of the SIEs they are designing; in turn, including a larger number of smart objects makes them feel more satisfied with their creativity because they are more aware of what they are really creating.

In the rest of the cases, there were no statistically significant correlations for the *Explorative* (CA: r = .268, *p =* .141; smart objects: r = .286, *p =* .125), *Tactile* (CA: r = .175, *p =* .244; smart objects: r = .050, *p =* .422) and *Tangible* (CA: r = .251, *p* = .157) systems.

* + 1. Participants’ satisfaction

The third questionnaire revealed differences on how the participants considered the systems in relation to *completeness*, *usefulness* and *ease of use* and their overall preference on one of the three systems.

Regarding the completeness, the *Explorative* and *Tactile* were considered the best systems (*Explorative* x̅ = 1.72, *Tactile* x̅ = 1.78, *Tangible* x̅ = 2.50), with some significant differences (*χ*2(2) = 7.778, *p* = 0.034): *Tactile* was significant better than *Tangible* (*Z* = -1.960, *p* = 0.050) and the *Explorative* was significant better than *Tangible* (*Z*=2.854, *p* = 0.004). Regarding the usefulness, the *Explorative* and *Tactile* were considered the best systems (*Explorative* x̅ = 1.83, *Tactile* x̅ = 1.78, *Tangible* x̅ = 2.39), with significant differences (*χ*2(2) = 4.111, *p* = 0.128), even if the p‑value was slightly greater than the 0.1 threshold the *Tactile* system was better than *Tangible* (*Z*= -1.824, *p* = 0.068). Regarding the ease of use, the system ranking was quite similar (*Explorative* x̅ = 1.89, *Tactile* x̅ = 2.06, *Tangible* x̅=2.06) without significant differences (*χ*2(2) = .333, *p*=0.846).

These results were confirmed by the way participants voted for the best system: the *Tactile* got 9 votes, the *Explorative* 6 votes and the *Tangible* 3 votes.

* + 1. Qualitative analysis of focus group discussions, open questions and observer’s notes

Different themes emerged from the analysis. The first one regards the importance of the phase focusing on the SIE conception. A couple of participants said that “*it was very useful to merge different opinions and convey toward a common idea that satisfies both of them*”. It also helped them “*create a mental order*” and “*translate the SIE ideas into custom attributes useful for the design*”. This activity was very beneficial for creativity, since they were “*stimulated to focus on the goal of their SIEs without worrying about the technical details of its implementation*”.

Regarding the use of the *Tactile* system, many participants said that it was their favorite choice. This is in line with the ranking resulting from the system voting. Simplicity, interactivity and collaboration were recurring keywords the participants used to underline how this system was simple and engaging, especially for collaborative tasks. The physical surface of the display was considered a “*useful space to sort out the ideas*”. Also, the interactivity of the tabletop combined with the manipulation of tangible attributes creates overall a more pleasant interaction. A problem some participants highlighted regards the size of the virtual keyboard, sometimes “*too large and thus overlapping and hiding important parts of the user interface*”. They also stressed two remarkably limiting factors for the adoption of this type of system in real contexts: its price and the required physical space to install it.

The *Explorative* system was appreciated because “*it is very simple to use*”, “*it is a very cheap and compact solution since it requires only a smartphone*”. The participants also said that “*it simplifies the association of custom attributes to smart objects with a big size*”, like a painting. Participants affirmed that its explorative nature can stimulate new ideas of attributes when they explore the environments. It was also perceived as “*very similar to the archaeologist work*”. About the disadvantages, a couple of participants said that the small size of the smartphone screen does not provide a wide and clear overview of the smart objects and their custom attributes. Indeed, even though users can see the overview in a summary section, its fruition is not so immediate as in the other two systems. They suggested the adoption of a tablet instead of a smartphone to enlarge the display area for the augmented reality layer.

Regarding the use of the *Tangible* system, the participants appreciated the small size (a participant said that “*it can be placed in a box after each use as a board game*”) and the reduced cost, which is an important factor in CH domain. The use of post-it notes makes the participants feel freer during attribute creation, even if they have to perform two actions (writing the attributes and take the picture) - while in the *Tactile* system they perform just one action. They liked the possibility to take a picture for digitalizing the physical composition: a couple of participants said that this feature is “*magic*” and “*useful*” since they can focus on the creation and association of the attributes in a “*physical way*”, similarly to the modus operandi adopted during the first phase, thus more prone to the conception. The participants also appreciated the fact that they could create compositions in the physical word since they “*can use a desktop that is larger than the tabletop surface*”, and to associate more attributes at the same time and keep an overview on them. Regarding the limitation of this system, the participants highlighted that the attributes’ creation with the *Tactile* system was slower due to having to manually write a name and value on a post-it note.

They also discussed the use of the *tangible attributes* in *Tangible* and *Tactile* systems. They proposed additional tangible attributes, e.g., a meter to specify numbers indicating measures, since the dice specifically evocate numbers used for game points. In addition, they observed that the physical representation of the attributes is important to stimulate the generation of new attributes. For example, a participant said that “*the dice suggested the possibility to introduce points and to modify the visit as a serious game*”, while another participant said that “*the compass suggested the introduction of locations*”.

The qualitative analysis has pointed out different results from the quantitative analysis. In fact, while the analysis of the data collected through the final questionnaire showed that the participants preferred the *Tactile* system, during the focus group its onerous costs and its encumbrance in environments, that are usually not very large, emerged. The same happens respect to the *Exploration* system: the participants expressed their skepticism about the installation of pre-labeled QR-codes in the environment and therefore it may require extra resources from museum curators. We believe that this difference derives from the fact that the first time the participants expressed their preference on the systems was at the end of the study and, thus, they judged their new experience with three different and innovative ways to create a visit. While during the focus group the participants had the opportunity to discuss and consider the constraints, especially economic of their work domain, and this led them to express a more thoughtful opinion.

All the participants agreed that the three systems helped them reach the goal of designing SIEs. For the adoption of one of them in real contexts, considering costs, attractiveness, usability, and required physical space, there is not a clear preference. However, the most interesting and unpredicted theme regards the *combined use of the systems*. Most of the participants proposed to combine the systems depending on different factors. The *Explorative* system, for example, can be also used during the excavation campaigns to catch useful attributes that can be refined in the office by using the *Tangible* solution. If a *Tactile* system can be used, the participants proposed to start the implementation of the idea by using this system and then enrich the SIE by exploring the environment to receive new stimuli for attributes not yet defined.

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