Extending Museum Exhibits by Embedded Media Content for an Embodied Interaction Experience

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ABSTRACT
This paper presents the results of an interdisciplinary applied research project about the application potential of ubiquitous computing concepts and technologies for knowledge transfer and exhibition design in museums. By interweaving mediated information directly into the context of exhibits and by transferring knowledge through discovery-based embodied interaction, we intend to overcome problems of distraction and social isolation, normally caused by handheld devices and graphical user interfaces. Applying scenario-based prototyping with a distributed hardware system allowed us to evaluate three case studies at three renowned Swiss museums. During the development and the evaluations, we followed five design principles that led to insights relevant for museums, design practitioners, the HCI community and technology developers. We concluded that the approach generates surprising experiences that have to be balanced with the exhibits and are very useful for explaining complex processes and functions, but cannot be implemented as an exclusive exhibition concept.

Author Keywords
Ubiquitous computing; internet of things; museum studies; exhibition design; sensor-actor-network; HCI; UX; usability study; spatial storytelling; context awareness; location sensitivity.

ACM Classification Keywords
H.5.1 (Multimedia Information Systems), H.5.2 (User Interfaces), H.5.m. (Miscellaneous).

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INTRODUCTION
Nowadays, museums not only collect, categorize, preserve and present; a museum must also educate and entertain, all the while following market principles to attract visitors. To satisfy this mission, they started to introduce interactive technologies in the 1990s, such as multimedia terminals and audio guides, which have since become standard for delivering contextual information. More recently there has been a shift towards the creation of personalized sensorial experiences by applying user tracking and adaptive user modelling based on location-sensitive and context-aware sensor systems. However, the technological gadgets and complex graphical user interfaces (GUIs) themselves generate separate information layers that isolate and detach visitors [24] from the actual exhibits and often eliminate a shared experience with other people [10,19]. The visitor's attention is drawn to the screen and the interactive technology becomes an element that competes with the environment and the exhibited collection [30,31].

In the wake of studies about museum visitor behaviour throughout the 20th century [18,20], a significant body of ethnographic research about visitor experience of single persons and groups has more recently contributed to studies about technologically extended and interactive installations. Publications about visitor motivation, circulation and orientation, engagement, learning processes, as well as cognitive and affective relationship to the exhibits are of special interest for our research approach [3,5,6,30]. Most relevant are studies of the human computer interaction (HCI) researcher community in the fields of ubiquitous computing (ubiComp), Internet of things (IoT), tangible user interfaces (TUI) and augmented reality (AR), investigating hybrid exhibition spaces and the bridging of the material and physical with the technologically mediated and virtual [1,12,19,31].

At our institute we have conducted several design research projects applying AR for cultural applications [7,26,28] but got increasingly frustrated with disturbing GUIs and physical interfaces such as mobile phones and head mounted displays. We therefore started to experiment with ubiComp, Internet of things (IoT) and physical computing technologies

[22,25,27] that have become more accessible for the design community over the last twelve years because of shrinking size and price of sensors, actuators and controllers. In the present research project, we therefore examine the extension of museum exhibits by physically embedded media technologies for an embodied interaction experience. We intend to overcome problems of distraction, isolation and stifled learning processes with artificial interfaces by interweaving mediated information directly into the context of the exhibits and by transferring knowledge through discovery-based embodied visitor interaction.

Our research approach is interdisciplinary and practice-based [14] including the observation of concept, content and design development and technological implementation processes before the final evaluations. Our engineering partners developed a distributed hardware environment and content management system (CMS) to implement three case studies at three renowned Swiss museums. Partners from the disciplines of human computer interaction (HCI), museum studies and exhibition design elaborated scenarios and qualitatively evaluated case studies with visitors in staged visits. The results of this paper derive from observations, visitor interviews and inquiries of the museums as well as external exhibition experts.

We followed five design principles, to setup and study the proposed approach: 1) physical exhibits are contextually extended by interactive media installations, 2) dramaturgy is discovery-based and builds upon embedded add-ons, 3) knowledge is situational and non-hierarchically organized, 4) interaction is embodied and 5) technology is distributed and incorporated.

The fieldwork led to general insights relevant for museums, design practitioners, the HCI community and technology developers. It showed that the approach involved the visitors emotionally and that they appreciated the discovery-based information retrieval. However, the strategy to deliver all information necessary for an exhibition through independent fragments and anecdotes without an underlying hierarchical structure was not entirely successful. Our museum partners assessed the approach as intriguing but would only implement it as a discreet additional layer for e.g. storytelling or as a tool to explain complex structures or functionalities.

RELATED WORK

According to our investigations, embedded interactive media for embodied interaction on cultural heritage sites most significantly relates to the HCI disciplines of AR, ubiComp, TUIs and media art. During the first decade of this century, various AR research projects for Greek ruins, subsidized by the *EC's Framework Programs*, had a strong impact on the use of AR for cultural heritage. Although in our research approach we reject handheld and head mounted information displays, context awareness and the bridging between physical object and mediated extensions are key notions, as much as they are in AR. In this field we can rely on our own experience and on more recent work like for instance the AR approach of mobile projection devices for children [16]. Furthermore, pervasive games are a fruitful playground for contextual positioning of mediated content [2]. Augmentation by way of spatial video mapping becomes increasingly relevant for cultural heritage too. Most commonly, it focuses on matching accuracy and calibration processes and the texturing of architecture models [21] or the projection onto city facades [13], but it can be applied with today's cheaper and smaller projectors onto objects just as well.

The focus of ubiComp research in the context of cultural heritage has often been concerned with problems of adding additional information layers displayed on text boards and mobile devices [8]. An important reference research project is the ubiComp-based exhibition "*Re-Tracing the Past"*, where information is linked to daily objects and media devices and discovered by test persons [11]. In ubiquitous learning, relevant studies have been conducted with children in exhibitions that are setup with ubiComp or IoT technologies going along with TUIs [4,29,32].

TUI research projects often focus on social exchange and cooperative work with physical interactive objects that bridge the physical and the virtual world [15,17]. Hornecker and Buur [12] distinguish between three disciplinary viewpoints on tangible interfaces and embodied interaction: *"a data-centered view, pursued in Computer Science and HCI; an expressive-movement centered view from Industrial and Product Design; and a space-centered view influenced from Arts and Architecture"* (p. 2). The latter is most relevant for our investigations because we follow a full-body interaction approach without interactive gadgets.

Wakkary and Hatala [31] investigated contextual aspects of TUIs, situated-play and discovery-based information retrieval using an audioscape system. They concluded that imagination and interpretation link the content to the artefacts. Since we intended to compose knowledge through information snippets that are dispersed in exhibition space and need to be mentally connected, the exploration of spatial information flow is also important. An interdisciplinary team of the *Mixed Reality Laboratory* (*University of Nottingham, UK*) and the *Centre for Intermedia, Department of Drama (University of Exeter, UK)* stated: *"Trajectories appear to be continuous, extending backwards in time to reveal a coherent history of experience, and forward in time to suggest anticipated routes and possible future actions"* [1]. Publications that proceed from the *meSch project (EC's Seventh Framework Program)* have also brought valuable insights [19]. Similar to our approach, research through co-design allowed the team to not only carry out visitor evaluations in existing exhibitions but also to analyse processes of content and dramaturgy development with technological tracking systems. They addressed concrete design problems such as: *"[…] automatic triggering that does not require explicit interaction […] can be confusing if*

[…] visitors do not understand how their body controls the system" (p. 2, ibid.)

Since the media interventions are very situational and in close spatial relation to the exhibits, projection-based artistic media installations creating poetic shared social spaces for cultural heritage also supply valuable knowledge [23].

STRATEGY AND OBJECTS OF INVESTIGATION

To gain insights into design principles of exhibition making with ubicomp technologies and to test the content management and hardware node systems developed exclusively for this aim, we set up three thematically distinctive case studies in specific exhibition situations. The three museums involved, the *Swiss Open-Air Museum Ballenberg,* the *Roman City of Augusta Raurica* and the *Museum der Kulturen Basel,* all have in common that they exhibit objects or rooms that function as staged knowledge containers and can therefore be extended by means of ubiComp technologies.

In the following, the investigation topics, sensor-actor installations and trajectory frameworks of the three case studies are described and illustrated by ground floor plans.

Figure 1. / 2. / 3. The Roman trade centre *Schmidmatt*. / The farmhouse *Uesslingen*. / The mandala (textile scroll).

Case study 1: *Roman City of Augusta Raurica* (RAR): "The Roman trade centre *Schmidmatt*"

Augusta Raurica was a Roman colonial city located in today's northern Switzerland. During Roman times, the trade centre *Schmidmatt* was a hotel and restaurant run by a family and their slaves. It burned down in 230 A.D. Since 1987, a shelter house protects the well-preserved ruins of the building, but some interesting archaeological finds can only be seen from a visitor viewing platform. The museum wants to improve the situation by allowing visitors to experience the site by entering the terrain, walking on protective walkways and is interested in offering additional information through attractive, innovative means to immerse visitors in the Roman era.

The primary imparting concept was "oral history", and documentary film served as a related model: An archaeologist, present during the excavations in 1983/4, acted as a virtual guide, giving visitors information about the excavation and research methods, findings, hypotheses and reconstructions. The ruins were staged by contextually placed video mappings, audio sequences and well-orchestrated illuminations of findings.

An information board at the entrance of the shelter building offered a general introduction to the ruins and informed about the media installation and the modes of interaction. There were no indications of the interactive triggering points in the exhibition. When entering the shelter house, the visitor triggered the first scene (TP1, directional motion): sounds of animals and backyard activities from the patio of Roman times. Prototypical walkways firmly guided the visitors through the ruins. Going to the right, the visitor triggered a projection of the virtual guide explaining the findings of some altar figurines (TP2, directional motion). Going back to the left, entering the former cellar, the visitor had several options to choose from: TP3 (distance) offered a 3D-projected explanation of the functioning of the hypocaust (roman floor and wall heating), TP4 (directional motion, when touching a figurine) triggered the flickering illumination of the hypocaust oven and a video projection staging the source of the fire incident, and TP5 (directional motion) explained the pottery store by means of illumination and a floor projection of sketches of the pottery findings in the correct position.

Figure 4. Prototypical walkway.

Figure 5. 3D-projection onto the hypocaust allows "x-ray view" to understand the construction of the heating.

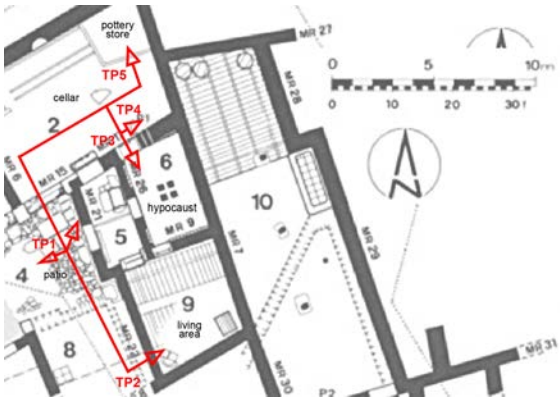

Figure 6. Ground floor plan indicating walkways and triggering points.

Case study 2: *Open-Air Museum Ballenberg* (OMB): "Farmhouse *Uesslingen*"

The *Swiss Open-Air Museum Ballenberg* proposed to technologically augment the furnished farmhouse from Uesslingen, built in the Eastern Midlands of Switzerland in 1568 and relocated to the museum in 1976. The history of the farmhouse is well documented, including construction phases and detailed information about the inhabitants. Up to now, elderly visitors have been able to explain many aspects of the historic site to succeeding generations. This generation

is now slowly disappearing, and novel forms of knowledge transfer become increasingly important.

By telling the stories of the house's former inhabitants, additional information about Swiss farming culture came alive and became emotionally engaging. The main design investigation topic was "narrative structures" and the main theme was "alcohol". In four rooms of the living area, visitors could experience small-sized, poetic, interactive media interventions, which were neatly incorporated in the furnishings to stage facts and critical aspects of historic rural Swiss society.

An information board at the entrance of the building offered a general introduction to the farmhouse and its former inhabitants and informed about the media installation and the modes of interaction. There were no indications of interactive triggering points. When entering the building, the visitor could not pass without triggering the first scene (TP1, directional motion): locally referenced sounds of cooking from the kitchen. The scene worked as a teaser to confirm the announced interactive installation and to create curiosity to explore. Attracted by the sound the visitor could trigger the next scene wandering around the kitchen table (TP2, directional motion): old recipes were projected onto an open book on the table. A bottle on the table, when being touched (TP3, capacitive), gave further information about the kind of alcohol that was used for cooking. Afterwards, the visitor could have entered the door of the storage room (TP4, directional motion) triggering movements of the shelves (motor motion), sounds of playing children from the floor above and lamentations of an alcoholic (presumably laying behind the shelves). Entering a circle of shoes (representing people) placed in the living room (TP5, distance), the visitor could trigger a dispute about the use of alcohol in rituals and religion. The content of the dialog was underlined by illumination of the shoes and insigne of religion. When standing in front of the right bed in the bedroom (TP6, directional motion), a sickbed scene was displayed, where alcohol was used to cure: the bed was messy, animated stains were projected onto the sheets and medical tools were illuminated.

Figure 7. Circle of shoes and insigne of religion.

Figure 8. Bedroom with video projected stains and illuminated medical utensils.

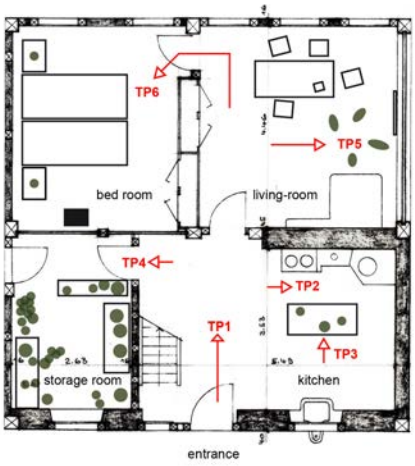

Figure 9. Ground floor plan indicating possible visitor paths and triggering points.

Case study 3: *Museum der Kulturen Basel* (MKB): "*meditation box*"

The ethnographic *Museum der Kulturen Basel* proposed the *"meditation box"* case study, which is part of the long-term exhibition *Strawgold. Cultural Transformations Rendered Visible.* The "*meditation box"* encourages visitors to contemplate a historic mandala (Asian visual meditation aid) and get an introduction to meditation methods. The MKB aims to become a place of encounter, inspiration and self-reflection by creating links to the here and now. The new technological approach of the research project aims to make foreign cultural practices more accessible.

The room-sized box was composed of a round sofa and a mandala suspended behind a semi-transparent textile screen. The textile served as a projection screen but also allowed the mandala to be seen through it when backlit. Two interaction devices were offered to the visitors: a touch-sensitive handle in the shape of a lotus pedestal and a biofeedback chest belt to measure breath activity. The main design investigation was "visitor participation."

An information board at the entrance of the box offered a general introduction to meditation aids and informed about the media installation and the modes of interaction. When entering the darkened box (TP1, directional motion), a voice welcomed the visitor and gave instructions about the possibilities of information retrieval. The sofa invited the visitor to sit down and to contemplate the illuminated mandala. When touching the illuminated lotus pedestal (TP2, capacitive) located next to the sofa, an explanatory animation was projected onto the screen making direct reference to the mandala behind it. The visitor could also put on the chest belt (TP3, stretch) attached to the sofa to interact with a real-time gamification of her/his breathing regularity.

Figure 10. Sofa with attached interfaces: touch-sensitive handle and biofeedback chest belt.

Figure 11. Mandala behind semi-transparent textile with projected video animation explaining its functions.

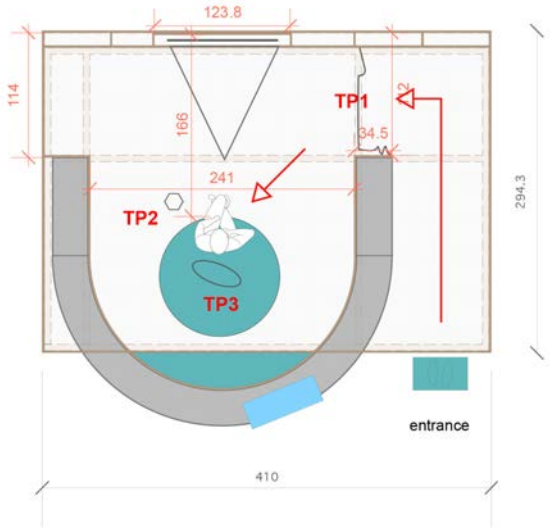

Figure 12. Ground floor plan indicating interaction devices and triggering points.

DESIGN PRINCIPLES

For the development of the case studies and the visitor evaluation design, we followed five design principles. The imposed conditions are superordinate and later also used for structuring the findings. They refer to the following main subjects: exhibits, dramaturgy, knowledge transfer, interaction and technology.

1. Exhibits: contextually extended by interactive media installations

All media extensions were closely related to at least one exhibit establishing a direct link. We invisibly embedded media technologies: no mobile devices, no touchscreens, no displays, no headphones. In their place we worked with distributed and hidden: projectors (for projection mappings or small projections without projection canvases), speakers (for spatial soundscapes), lamps (for illuminated exhibits) and servomotors (for kinetic objects).

2. Dramaturgy: discovery-based, built upon embedded add-ons

We did not use any superordinate guide system to indicate interactive hot spots but gained visitor attention by way of teasers implemented as sound sources, illuminations and projections. Visitors explored a seemingly technology free environment and triggered mediated scenes through embodied interaction.

3. Knowledge transfer: situational, non-hierarchical, non-linear

We did not organize the added information as a linear hierarchical education experience. The casually triggered information snippets could have any depth, level of complexity or detail but all summed up generated the bigger picture. Only the situational orchestration suggested the significance of a casual anecdote, a detailed information about an apparatus, or the historic background of an entire scene.

4. Interaction: embodied, embedded

To explore the potential and limitations of TUIs for our approach, we introduced at least one example per case study.

Otherwise, we used no interactive input devices other than the human body and no user interface other than physical space. To not distract the visitors from the exhibits we implemented no GUIs. Test visitors triggered mediated scenes by passing-by, getting close enough and staying long enough.

5. Technology: distributed, incorporated, varying

The implemented sensor-actor network was modular and adaptable and allowed monitoring and maintenance (CMS). We tested different combinations of media technologies, such as: illuminated exhibits illustrating voice-overs, projected video onto corresponding surfaces, complementary sounds along a passage, build-up of scenes composed of sound, light and video.

METHODS AND INVESTIGATION TOPICS

To establish a basis, the project was setup with three case studies covering a wide range of aspects under varying conditions. We applied qualitative research methods to collect data of how experts assessed and end users perceived the alternatively staged information.

For the content and design development, we followed a scenario-driven prototyping approach. We created criteria catalogues and technological requirement profiles based on initial inquiries with the museums and design partners. Through a participatory design process, we subsequently developed scenarios for each case study, suitable for walkthrough with several test persons. Comparable and complementary case study scenarios allowed us to identify risks and opportunities for exhibition design and knowledge transfer and to define the tasks and challenges for technical implementation.

First, we conducted usability studies in prototypical research setups at the Media Lab and later carried out on-site visitor evaluations at the museums. During the usability studies, we focused on investigation topics such as visitor orientation, information processing and comprehensibility, interaction processes, media design, media technologies and the augmentation potential of different types of physical exhibits. These investigation topics were extended during the

following visitor evaluation with subjects such as: dramaturgy in the museum's context, user experience, attractiveness, emotional involvement and depth of information. Problematic multi-user situations, that could have created conflict of interest during the triggering of content, were not in the centre of attention and were avoided by the spatial media setup of the scenes. With final museum inquiries, we gathered our partners' feedback on their overall experience and the assessment of the project's approach and its applicability.

Our goal was not to distinguish between different types of target groups, but to find fundamental tendencies to derive design principles. We therefore invited test persons of various genders and ages (including families with children), who had varying levels of technical understanding and little or no knowledge about the project. Beside the end-users, we also invited experts and in-house museum personnel. We informed the subjects that they were participating in a visitor evaluation of a design research project and asked them to explore the setting as long as they wanted (normally 10–15 minutes). They agreed to be observed and video recorded during the walkthrough and to participate in a semi-structured interview afterwards. We carried out the following visitor evaluations (feedback origins are indicated by our museum abbreviations: OMB = Open-air Museum Ballenberg, RAR = Roman City Augusta Raurica, MKB = Museum der Kulturen Basel.):

- OMB: 9/10/11 September 2016. 4x end-user (2x family, 2x single), 3x external museum expert, 2x member of museum personnel
- MKB: 8/9 November 2016. 3x end-user, 3x external museum expert, 1x member of museum personnel
- RAR: 13/14 March 2017. 2x end-user, 2x external museum expert, 3x member of museum personnel

The evaluation settings of the OMB and MKB were also open to the public for several days (and partially still are). We therefore also asked the supervisory staff about their observations and mingled with regular visitors to gain insight into their primary reactions, comments and general behaviour. This was of special interest at the OMB since visitors entered the farmhouse from Uesslingen after they had been through many other houses on-site and were not aware of being part of an evaluation. The evaluation was followed by a heuristic qualitative content analysis of the recorded audio and video files and the notes we took during the interviews.

Figure 13. Visitor evaluation at the *Open-Air Museum Ballenberg.*

OBSERVATIONS AND FINDINGS

In this section the most valuable results of the usability studies and evaluations are presented along with the three case studies and the five design principles.

Case study specific insights:

Case study 1

The scenes were set up in the ruins of the Roman trade centre *Schmidmatt*, in an open landscape-like area with just a view staged reconstructions, and accessed only by walkways. Free exploration of the environment was therefore limited, but most visitors appreciated the walkways as a spatial orientation means. Although more foreseeable, the triggering of scenes when passing by still offered an element of surprise.

The introduction of the archaeologist as a virtual guide and oral history witness worked out well, but some test visitors wished the character had been introduced more in-depth at the beginning. However, the life-sized projection and the recognizable voice established the character during the walk. The life-sized projection onto the walls created (under willing suspension of disbelief) the illusion of a human presence and helped to attractively present information that otherwise would have resulted in large text boards.

We also installed a TUI (a little statue of the Roman God *Vulcan*) on the handrail of the walkway prototype to evaluate if test visitors would dare to touch it, being in a museum context. They actually did so since the figure obviously was an abstract symbolic element (purely white 3D print) of the walkway, an interface rather than an exhibit.

Case study 2

The indoor space of the farmhouse *Uesslingen* is abundantly staged by props containing information about the life of bygone times and offers a rich setting for storytelling. We distributed interventions that appeared to immediately withdraw again, to leave enough space for the physically outfitted rooms to unfold in their own right. We decided to stage stories about fictive persons in different time periods (covering 200 years) all referring to the central topic "alcohol". The abstract scenario approach was ultimately not explicitly comprehensible to the visitors. As if watching a

feature film, test visitors tried to invent a context that tied together the spatially located scenes and the characters involved. Most interviewees felt there lacked a clearly recognizable structure with well-introduced characters and their correlations for a coherent picture at one point in time.

The visitor was always the silent witness and never addressed directly. Some test persons liked the passive observer perspective; others wished they had been more involved and felt a staged character to identify with was missing. We concluded that to gain the visitors' attention and willingness to enter a story, it would be necessary to fully introduce the story.

Case study 3

The exhibition space of the "*meditation box*" was too small and dark for full-body interaction and was therefore not evaluated for its spatial interaction trajectory. Instead, the focus was on the augmentation of a single object: the mandala. Visitors did not trigger events by passing-by, but were directly addressed to participate. Consequently, the timing of appearance and disappearance of the offered extensions by means of illumination was crucial.

Projecting animations onto a semi-transparent textile in front of the mandala allowed to establish direct context to the representations of the mandala. Extracting elements of the textile scroll in high resolution photos enabled the visitors to see and focus on things they would not have with the naked eye. However, projecting light onto delicate exhibits can be difficult and projections onto semi-transparent textiles partly obscure the exhibit.

Findings structured along the five design principles:

1. Exhibits

Concerning media-extended physical exhibits, three aspects are of special interest:

Ephemeral media presence: Since we consider exhibits to be knowledge containers that deserve a thoughtful treat, we declined interaction concepts that use an exhibition merely as a stage for complex storytelling or an extensive media show. Instead, we only temporally extended them with media add-ons and investigated the poetics and aesthetics of an ephemeral hybrid experience. Our museum partners appreciated that the main impression of the exhibition was purely physical and that the mediated information was only visible when triggered by a passing visitor by.

Bridging the physical and the mediated: We investigated the augmentation potential of different types of exhibition situations. Smaller exhibits need to be isolated or highlighted (illuminated) when being part of a dense setup. Sounds have to be precisely positioned and the volume must vary in order to help differentiate whether the information is relevant for a small detail or an entire space. Video projections can also be small and positioned directly besides the exhibits or on walls and floors for more general information. We did not use any canvases, but the projections need an adequate free surface and space. *"I liked how the wall was untouched again when the projected person disappeared"*. However, those spaces must not appear needlessly empty when the projection is at rest. We also discussed to what extent scenes should be physically staged to bridge the media extension (e.g. the pottery cupboard reconstruction at RAR). It is a fluent passage between the exhibit and the media extension, which is why physically staged or reconstructed elements can weaken the exhibit as much as the media extensions.

Spatial video mapping: Projection mappings directly onto the exhibits were rated very positively. The projection of the building construction of the hypocaust onto the hypocaust floor and wall (RAR) and the explanatory video animation onto the mandala (MKB) were the most successful video extensions. In both cases, the media extension revealed valuable information superimposed onto the exhibit. Visitors and museums considered that the approach offers new ways of explaining complex processes, functions or coherences, since visitors do not have to switch between the exhibit and a representational information layer: *„I consider this info station the most powerful, since the technology is implemented appropriately. The animation could be improved but the impression of the x-ray view worked very well."*

2. Dramaturgy

Based on the media-extended physical exhibits we explored various dramaturgical aspects:

Emotional involvement: The media extensions helped the visitors to better immerse themselves into bygone times and to emotionally connect and identify with the past. We confirm what Wakkary and Hatala [31] concluded, that imagination and interpretation link the content to the artefacts. Moreover, personal knowledge, associations and memories come into play. One visitor mentioned: *"Combined with my own knowledge and memories the objects came alive."* Another one considered: *"I think the direct context (to the exhibit) helps to better remember the information."*

Discovery-based information retrieval: During test runs with indicated triggering points, we observed that visitors started to look for the interactive hotspots. We had just introduced another interface, one that again distracted visitors from the exhibits in their search for hotspots. From then on, we no longer used guide systems to indicate interactive hot spots at the museums. The moment of surprise was never a problem for the test persons, quite the opposite: *"I enjoyed exploring and I guess especially for children it must be fun."*

Dramaturgy of the add-on: Our museum partner OMB opted for a visitor experience in which the mediated content is an attractive add-on to involve visitors emotionally but contains no basic information. Modest storytelling scenes – like the bedroom with clues of a medical intervention – were considered most impressive and described with terms such

as *"subtle", "sensitive", "evocative"* and *"emotionally involving."* The media setup was simple, however: interactive illumination of medical utensils and projection of stains onto the sheets. The scene was thus ambiguous: *"Was it a scene of childbirth or illness?"* Some test persons found the scene *"frightening"* or even *"disrespectful towards the former inhabitants"*. This confusion caused strong emotions, since the visitors became witnesses to an intimate moment. They became thoughtful and carefully analysed the scene.

Experts estimated that the presented information was not too scholastic but, e.g., included anecdotes of daily life or details of utilization or cultural value. This is especially important if the information is referential to an exhibit. The exhibit should not simply be a triggering symbol for general information; it ought to reveal a specific detail that makes the information situationally perceivable.

3. Knowledge transfer

The decision to only deliver discovery-based knowledge by exhibit add-ons has considerable implications:

Loss of information: It was expected and confirmed that scenes might be missed out on because of lack of attention or appearing too modest to draw attention. Important scenes should therefore be staged along main passageways to trigger the attention of observant visitors. However, subtle scenes with little presence might get lost, but if they are discovered by an attentive individual, they generate a very strong intimate moment. One can argue that not all visitors have to consume all the content; instead, the loss of information might have to be compensated by a surplus of information and additional production costs. These results shows that discovery-based information display is rather useful for generating experiences and memories and less effective at delivering solid background information.

Non-hierarchical information dissemination: Our approach made no difference between a casual anecdote, detailed information about an apparatus or the historic background of the entire scene. This made the scenes casual and took the scholastic weightiness from them. Some experts encouraged us to add more situational details or anecdotes of social and cultural values rather than historic facts or clichés to make the scenes more emotionally tangible. But delivering significant information solely by insinuating special and unexpected details that are closely related to the exhibit is also problematical. Most interviewees felt there lacked a clearly recognizable structure. A museum expert at the RAR complained: *"Some info hotspots contain too many quickly delivered and mixed types of information. Why do you explain the history of the whole building in the corner of the pottery cupboard? I think it is the wrong place. It should be explained in the beginning or at the end."* He proposed to subdivide information into several layers and hotspots with different levels of information: e.g. historic context in Roman times, location and work during excavations, excavation techniques, findings, comparison with other findings, interpretation and significance, reconstruction, conservation or contextualization. The intention of the project was to avoid a hierarchical information structure, but we found out that through variations of size, audio volume, situational positioning, etc. we could stage distinguishable types of information. However, an introductory information panel could deliver basic information before the actual walkthrough and relieve the hotspots from their task of delivering all the necessary information.

4. Interaction

We explored various aspects of embodied interaction:

Interfaces: We installed at least one TUI per case study to examine its potential and limitations for our approach. Since museum visitors are normally not allowed to touch exhibits and should not be encouraged to do so, TUIs have to be indicated as interfaces or hotspots. Even more, to be discovered they need to be clearly introduced as a consistent interaction concept throughout an exhibition. Therefore, we concluded that the use of TUIs for our approach of embodied interaction was not suitable.

Unconscious interaction: Embodied interaction is challenging since the visitor does not consciously interact by e.g. choosing a topic by pressing a button. Interaction only takes place in the physical environment and except for the TUIs no haptic objects came into play. Some visitors just enjoyed the magic, while others tried to find the sensors to actively influence on the scenes. Everybody in the Western world knows light triggering motion or distance sensors from house entrances or public toilets. We therefore observed a certain "interaction literacy" (as in media literacy) amongst our test persons. However, as opposed to the conclusions of the *meSch project* [19], we concluded that it is not necessary that museum visitors are aware of their interactions, nor should the mode of interaction draw too much attention, which distracts them from the exhibits.

Interaction design: When visitors enter a new room they first go through a process of orientation and appropriation. Information should therefore not be displayed immediately, especially if the media content has to be discovered first. The scenes therefore only got displayed if the visitor entered and stayed at the right location for long enough. They didn't last longer than approximately one minute and faded out earlier if the visitor moved on before they ended. The studies confirmed that interaction timing is crucial and differs according to the displayed content, media implementation and the spatial composition of exhibits and sensors. The software developers therefore implemented CMS functions that allowed the designers to adjust 1) reaction time, 2) inactivity time out and 3) new start after scene termination. These functions helped to optimize responsivity, avoid accidental interruptions and premature restarts of the scenes and helped to orchestrate a flowing visitor experience.

An interface for everybody: A positive aspect of embodied interaction is the fact that visitors do not have to interact with technical devices or learn how to operate GUIs, which means

that no user groups are excluded from the experience and information retrieval.

5. Technology

We explored different types of sensor-actor and actor-actor combinations:

Sensor application: Several interviewees found the technical implementations and interactions too obvious; motion and distance sensors were the most commonly applied sensors. Some visitors became aware of the sensors limited range and got distracted from the content by trying to trigger the scenes at various distances. They started to play with the (invisible) interface – precisely what the project's approach tried to avoid. Therefore, sensor types, their parameters, positon, direction and coverage have to be carefully chosen to avoid this kind of distraction.

Media settings: We tried out different types and combinations of media technologies for transferring knowledge. The combination of a voiceover and temporally corresponding spotlight illumination of the exhibits, for instance, worked very well as a bridge between physical exhibits and media content. The implementation of a motor for physical motion in combination with a voiceover also lived up to its promise: People were stunned, as media inputs like sound and video are more common. Also the build-up of a scene along a pathway, summing up information while a visitor is walking through the exhibition worked well, as examined in the Roman patio (RAR).

Media homogeneity: We found out that homogeneity in the media setting is important, because people expect consistency of experience. Test persons always expected the same paring (e.g. sound, light and off-voice) and thought that there were technical problems when one component was missing. Alternatively, the media composition could be extremely varied to make pattern recognition and expectations impossible.

DISCUSSION

By interweaving interactive, mediated information directly into the context of exhibits, we intended to overcome problems of distraction and social isolation caused by graphical user interfaces and handheld devices. The interdisciplinary practice-based development approach and the visitor evaluations gave insights into the three main investigation tracks:

- **Content development (museum studies):** The interdisciplinary content development process allowed for joint examination of contextual information delivery, diverse dramaturgical approaches and media constellations.
- **Design implementation (exhibition design):** Exhibition designers and curators gained insights into how to mediate exhibits subtly, guide visitors with an embodied interaction approach and how to orchestrate discovery-based knowledge transfer.
- **Technological requirements:** The technology developers learned what kinds of features are necessary for the museums to independently update their exhibitions and about the feasibility of technical integration on cultural heritage sites.

Due to the complexity of the project setting, with three case studies including a large range of topics, we only carried out small scale studies with small test groups. Based on these results a follow-up project with more focused research questions and quantitative research methods might be carried out.

The project showed that the embodied interaction approach and the media extended exhibits involved the visitors emotionally. They appreciated the surprising discovery-based information retrieval and there were no disadvantages for visitors with less technical understanding. However, we learned that it is challenging to deliver information as independent fragments and anecdotes without an underlying hierarchical structure. The better the basic topics are established before entering the audiovisually extended exhibition, the more freedom arises to build up the bigger picture by continuous accumulation of snippets and for the orchestration of poetic context-based information.

Our museum partners agreed that the approach should not be implemented as a central concept and dense setting for an exhibition. The approach should be applied as a discreet layer to emotionally transmit additional information or as a tool to explain complex processes, correlations or functionalities.

In this project we exclusively examined indoor situations, although of different size and character. Outdoor spaces would pose different challenges, especially for the technical implementation and the dramaturgy of a more sparsely populated media ecology. The walkway system we examined in the case study *Roman City of Augusta Raurica* could be a valuable outdoor approach. It is useful for protecting the ruins from visitor vandalism, as a guide system and for the incorporation of interactive devices and technical infrastructure. The development of a standalone, compact, modular catwalk system could also be an interesting applied research investigation topic.

CONCLUSIONS

With this study we want to contribute to the discussion about the design and the visitor's perception of interactively mediated museum exhibitions. The boundary condition for our approach was to examine exhibition situations without information boards or guide systems, without GUIs on handheld devices, without visible displays or tangible interfaces and to focus on discovery-based information retrieval trough embodied interaction. The findings about the fundamental potential and limitations of this approach are the major achievement of this paper.

The partner museums especially appreciated the potential of 3D animation mappings onto the exhibits themselves to

extract complex processes, functions or coherences in the immediate context. This led to new application ideas such as the explanation of structures and constructions, functionality of tools and gadgets, visibility of overlapping layers, scientific documentation and reconstruction processes, etc. A focus on this media approach might open up new research questions for a follow-up research project.

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