MIRACLE HANDBOOK

GUIDELINES FOR MIXED REALITY APPLICATIONS FOR CULTURE AND LEARNING EXPERIENCES

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1. INTRODUCTION

The purpose of this Handbook is to summarize the knowledge collected in the MIRACLE research project, and deliver application design guidelines based on the project results, all in one compact document. The Handbook provides a summary about possibilities of applying augmented and virtual reality technologies in cultural travel and education.

It includes

- *Guidelines for designing and building successful Augmented Reality applications*
- *Advice for experts in one profession about working with people of another profession*
- *Toolkit: a list of software components, tools and methods for developing augmented reality applications serving cultural travel*

INTENDED AUDIENCE

The Handbook is aimed at supporting museums and other cultural sites with historical and/or cultural value and interested in attracting general audience by augmented reality offerings. It helps the personnel of such organizations in choosing what kind of experiences would suit the particular case, and what resources are needed to make and maintain it.

Companies creating augmented reality/virtual reality (AR/VR) applications and content for cultural organizations are also potential audience for the Handbook. They should gain practical information about tools and methods that have been tried in the MIRACLE project.

Yet another target group are researchers (especially historians) interested in using AR/VR technology as a tool in academic work.

MIRACLE PROJECT

MIRACLE—*Mixed Reality Applications for Culture and Learning Experiences*—was a research project that was run between 1/2015 and 4/2017. It was an extension to the preceding *Futuristic History* project[1] of 2013–2014. The motivation for this research was based on the following facts:

- Museums need new attractions as the competition of people's time and interest is getting more and more fierce. Augmented reality can enrich cultural experiences and is therefore a potential means of attracting people to places that could otherwise be losing visitors.
- Interactive applications have educational potential, so general education could also benefit from the approach.
- Tourists routinely carry smartphones and tablets that can run the applications. There's not necessarily a need for major investment in new equipment at the site.
- Development tools are becoming easier and more affordable, meaning that the production cost for applications are decreasing.
- The project's intention was to develop ways for multidisciplinary team to create attractive, engaging mixed reality applications for cultural travel, to create knowledge clusters connecting professionals with different expertise areas, and to collect knowledge into a *Handbook* and a *Toolkit* that would be distributed openly.

A central objective in applying mixed reality technologies to touristic and educational use is to make the facts visible and help the visitor to understand them more easily and deeply than by traditional methods used in museums. Besides that, the project was also focused on human factors—engagement of the audience, entertainment factors and social interaction.

Research topics in the project included

- Developing cost-efficient tools and processes. This includes creating pilot apps for varying cases, mainly museums and memory organizations, and developing improved AR technologies for these uses.
- Studying learning experiences by AR applications. Learning is moving out of the classroom, and research shows that interactive learning methods are often more efficient than traditional teaching methods.
- Seamless connection with social media. Sharing experiences is important to people, and crowdsourcing can be used for collecting valuable knowledge about culture.
- Business models. Finding suitable business models for different kinds of cases was a target.
- Creating a network of potential actors in Finland.

Project duration was from 1/2015 to 4/2017. The research units that participated in it were

- University of Turku: Department of Future Technologies (formerly Technology Research Center) and Finnish History.
- VTT Technical Research Centre of Finland
- University of Tampere, Faculty of Communication Sciences (formerly School of Information Sciences)
- University of Helsinki, Faculty of Educational Sciences

The project was financed mainly by Tekes—the Finnish Funding Agency for Innovation. Other participating organizations were

- Amos Anderson Art Museum, Helsinki
- KOy Casagrandentalo, Turku
- The Chemical Industry Federation of Finland
- EnkeliGroup Oy, Raisio
- Evangelical Lutheran Church of Finland, Helsinki
- Finnish Aviation Museum, Vantaa
- Kilt Oy, Tampere
- Maritime Centre Vellamo / Museum of Kymenlaakso, Kotka
- Automobile and road museum Mobilia, Kangasala
- The Museum Centre of Turku
- Museum of Technology, Helsinki
- Muuritutkimus Ky, Kaarina
- National Board of Antiquities, Helsinki
- Turku and Kaarina Parish Union, Turku
- Vapriikki Museum, Tampere
- Vucom, Helsinki
- Nimble Devices Oy, Espoo
- Silencio Oy, Helsinki
- Bryggman Foundation, Turku
- Finnish Tourist Board, Helsinki
- Regional Council of Southwest Finland / Lounaispaikka, Turku

HANDBOOK CONTENTS

Chapter 2 describes the potential uses of mixed reality in museums and other cultural sites, and the pedagogical aspects involved in it. Multidisciplinary co-operation in MR creation and maintenance is discussed.

Chapter 3 concentrates in the actual production and maintenance processes, business opportunities and connections to social media.

Chapter 4 describes the individual pilot applications that were implemented in the MIRACLE project: how they were planned and built, what were the research targets and what was learned.

Chapter 5 summarizes the outcome of the project.

Chapter 6 describes the Toolkit, i.e. the collection of software tools and components tested and developed within the MIRACLE project.

References and related literature are listed at the end of each chapter.

A glossary is at the end of the document.

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2. MIXED REALITY IN TOURISTIC AND EDUCATIONAL USE

This chapter explains the basics about augmented reality, virtual reality and mixed reality. Some existing culture- and science-related applications around the world are introduced. The potential for using these technologies in cultural heritage related applications is discussed from different points of view: identified benefits in educational use are described, and financial aspects are analyzed. The need of cooperation between people of different skills is introduced.

2.1 WHAT IS MIXED REALITY?

Imagine yourself in an open-air museum consisting of 18 blocks of an 18th century city. The buildings around you are preserved on their original location. Every object is an authentic remnant of the past. Everything you see has something to tell about life more than 200 years ago. But yet, something is missing: the life itself. Streets are quiet and the buildings are empty with the exception of other visitors and guides. You experience more like a ghost town than life in the 18th century city. Imagine then that everything comes to life. You can see the people and the animals of the past and feel the bustle of the city. You can discuss with the people you meet and have an effect in what happens around you.

This is not a scene from a science fiction story, but instead, using a tablet computer, already reality in part at the Luostarinmäki Handicrafts Museum in Turku in 2014.

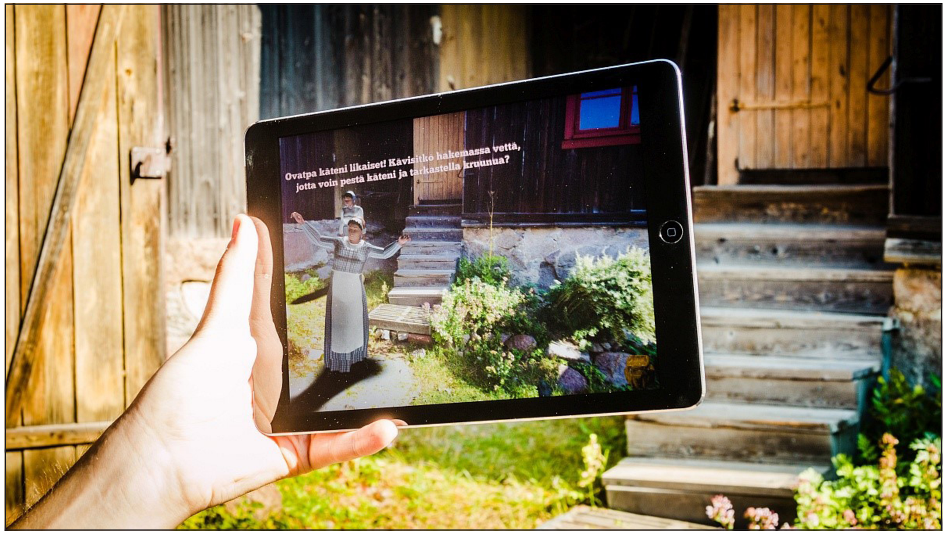

Image 1. Luostarinmäki Handicrafts museum, Turku, Finland.

An adventure game shows the museum visitor the life in the city in 1850's by combining the reality and the virtual, the physically existing contemporary buildings and digitally created characters.

Virtual Reality (VR) is an environment, created artificially, typically using computers, and presented to human users via various audiovisual displays. In principle, virtual reality may contain artificial stimuli for any human sense, but in practice the virtual environments nowadays are mostly limited to visual and auditive content.

In Augmented Reality (AR) the real world view is augmented with additional information. This can be computer-generated 2D and 3D images or information superimposed on the real-world view, seen through data glasses, or captured from the camera of smartphone, computer or other device. Augmented image appears to its users like virtual and real objects coexisted in the same space. In other words, AR immerses its users in virtually enhanced real world.

By definition of AR by Azuma[1], it has three characteristic elements: a) it combines real and virtual objects in a real (3-D) environment, b) it runs interactively and in real time, and c) it registers (aligns) real and virtual elements with each other.

Augmentation of reality has been used in different medias and systems for decades, e.g. head-up displays in fighter planes or scoreboards in sportscasts. Due to the computerisation and rapid emergence and development of mobile technology, AR is now available for common users in their mobile devices and possibly soonish with AR-glass technology.

Image 2. Head-up display in an aircraft.

Mixed Reality (MR) is the art and technology that is used to mix real-world elements with virtual reality. In the already classical virtual reality continuum by Milgram and Kishino[2], everything between the extremes of reality and virtual reality is called Mixed Reality. This area includes augmented reality as well as augmented virtuality, which means a mostly virtual environment containing some real elements. MR can use any or all the senses we have, from viewing and hearing (which are the more common methods) to tasting, feeling and smelling—even understanding balance. However, most actual mixed reality applications are limited to audiovisual content in the virtual part.

The interest towards the emerging AR/MR technology has been rapidly growing among the museums and cultural heritage sites around the world. However, the acceptance of AR/MR applications can vary in different populations. Lee & al[3]. made a cultural comparison between South Korea and Ireland, both having high smartphone penetration rates but different cultural profiles, and noticed that aesthetics of AR have the strongest influence on perceived enjoyment. Also, as expected, South Korea, having high collectivism and high uncertainty avoidance culture, displayed stronger dependence on social influence and hedonic characteristics of AR/MR.

Smartphone or tablet device meets the main requirements posed by AR since it has a camera and capability of rendering and displaying the augmented graphics. Hence, with explosive growth of penetration rates of smartphone, application-based AR has been more accessible to users.

Whereas virtual reality (VR) can deviate greatly from the real world, augmented reality productions however must fit into the physical context in order to achieve an immersive and believable experience. At the minimum a good AR application should:

1. **Seamlessly combine the physical and virtual pieces of content.** The first condition is not to set limitations to artistic freedom in any sense, but to highlight the fact that at least the virtual content should in fact react to as many changes and parts of the real world as possible.
2. **Be highly interactive in real-time.** The second condition separates for example pre-rendered movie productions from augmented reality, as even if the contemporary film productions feature highly believable computer generated imagery, they do not represent a real-time simulation of reality from the end-users point of view.
3. **Allow users to experience the content with free movement in the real world 3D space.** The third condition emphasizes that the end users must be able to move freely and explore the content from any angle and location they like. The virtual content must always be fixed tightly in its place in the real world while the user moves about.

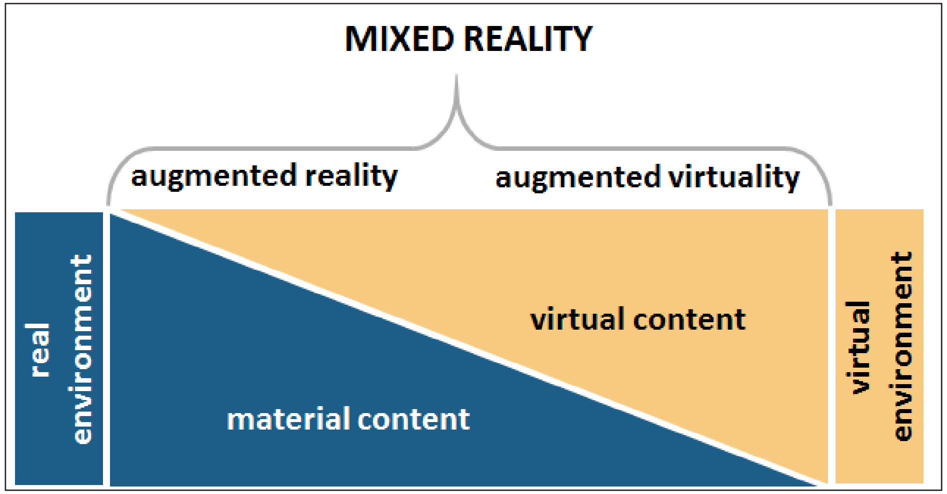

Image 3. Virtual Reality continuum.

AUGMENTED REALITY

- *a mixture of real world and digital illusions*
- *interactivity with the real environment*
- *on-line effects*
- *three-dimensional impressions*

MIXED REALITY

- *The combination of material world and virtual elements between real and virtual environments*

ON WHAT KINDS OF EQUIPMENT CAN MIXED REALITY APPLICATIONS BE USED?

Mobile devices (smartphones, tablets) have reached the technology level where they can offer satisfactory mixed reality experiences without any additional hardware. The built-in camera, movement sensors, compass and GPS receiver can provide location data accurate enough for many cases, and the computing capacity is often good enough to keep the lag in MR apps at a satisfactory level. The display presents the augmented view to the user.

See-through augmented reality glasses, like the *Microsoft HoloLens* or *Google Glass*, are another possibility of presenting augmented reality content. Compared to handheld devices, such glasses offer the advantage of freeing the user's hands, and the augmentations can also be seen over the real environment instead of the device screen. However, currently (Q1/2017) AR glasses are still an expensive rarity, and their display properties often leave room for improvements. But in not too far future we might see products that change the game, and then a boom of AR applications for glasses may be expected.

Augmented reality could also be presented via virtual reality glasses—also known as head-mounted displays, or HMDs—such as the *Oculus Rift* and *HTC Vive*. The display can show the real environment as video, adding augmented objects in the video feed. However, these displays obviously aren't truly mobile—they can only be worn in controlled, safe places, not when walking in the streets. They could be a feasible option in cases where the application would be used in a restricted place, and where the risks of collisions and other accidents are eliminated.

There is more detailed discussion about AR-enabled devices in Chapter 3.

WHAT CAN THE AUGMENTED CONTENT BE?

In principle, the augmentations can be derived from any information that is available and can be associated with the real world objects around the user. Imagination is perhaps the biggest limitation to what can be presented—AR can be used to entertainment as well as education, it can act as a guide or interpreter, and it can be used to help in decision making.

A common example is a travel application displaying indications of nearby restaurants and hotels, possibly with the price and rating information. Technically a similar example would be recognizing license plates of cars on a street and displaying their owners' names and addresses, if this information can be extracted over the internet.

A practical example presented in image 4 translates signs and labels from one language to another. The principle in this is to recognize pre-

Image 4. Augmented reality translation example.

defined objects from the live camera image and replace them on screen with other graphics, everything happening on the fly. This kind of application can be very useful for example in museums where additional translated signs would be a disturbance in the authentic environment. From technological point of view, the task requires the use of sophisticated computer vision algorithms and fairly powerful mobile devices. For the user, such applications offer a very easy-to-use replacement of a dictionary when visiting places in a foreign country.

Cultural heritage tourism is an example of a field that has already gained from MR technology. MR may help to prevent degradation of historical sites and offers the tourists enjoyable and useful access to cultural heritage. Major attractions such as the British Museum and the Louvre offer MR applications to their customers.

Especially narrative MR applications can be very useful in communicating historical knowledge to the public. MR technology can offer information and experiences that would be very difficult, even impossible to represent with traditional media used in museum exhibitions and heritage sites. All aspects of the past life are just not reducible to words, still images or other traditional means. Mixed reality can connect historical information with the material reality, making history visible in situ and thus make it more comprehensible.

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2.2 EXAMPLES OF EXISTING MR APPLICATIONS

These applications are—or have been—available for the visitors in some museums and other places of interest around the world.

Streetmuseum

Museum of London. AR app of historical photos[1]. The app displays historical photos in the actual locations, overlaid onto the current view. The app was released in 2010.

PIVOT

"Rediscover the history around you. Change your point of view." PIVOT[2] *(Point of Interest Visual Optimization Tool)* is a mobile app that reveals to users what places looked like in the past—showing authenticated histories of locations (from everyday places to popular tourist attractions), through images, videos, and text-audio. End users can also store and share their most pivotal moments through "shoebox archiving" (the method of digitizing memories and old shoeboxes of photographs).

Natural history applications

American Museum of Natural History. The museum distributes several mobile apps[3] for visitors acting as personal tour guide or presenting theme-specific information about exhibitions. Some of the apps are:

- *Explorer:* the general app, allows creating personal tours according to own interests, acts as a guide.
- *MicroRangers:* AR game to be played while in the museum. Scenarios involving microorganisms to be explored.
- *Dinosaurs:* photos and renderings of dinosaur fossils.
- *Beyond Planet Earth:* AR app to accompany the 2011 exhibition.

KSPACE

National Museum Australia[4]. The application encourages kids to explore the Museum by finding characters from the Kspace games. The app uses markers to launch the characters. The visitor is encouraged to follow a trail around the Museum and find all eight characters placed there.

ARtours

The Stedelijk Museum, Amsterdam[5]. The app allows you to experience interactive tours on your smartphone and enjoy the rich content (video, audio, photos, stories, tasks and Augmented Reality additions) as you explore the museum or the streets of Amsterdam.

Pokémon Go

Pokémon Go[6] was the game that brought augmented reality as a term to wide audiences around the world. While it perhaps did not fulfil all the definitions of augmented reality, it did give a rough idea about virtual creatures in a real environment to a huge amount of people.

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2. *PIVOT:* *http://www.pivottheworld.com/*
3. *American Museum of Natural History:* *http://www.amnh.org/apps/*
4. *KSPACE National Museum Australia:* *http://www.nma.gov.au/kspace/kspace_app*
5. *ARtours Stedelijk Museum, Amsterdam:* *http://www.stedelijk.nl/en/artours/artours-app*
6. *Pokemon Go:* *http://www.pokemongo.com*

2.3 MUSEUMS AND OTHER TOURISTIC AND EDUCATIONAL SITES

Museums and other culture-related attractions are competing fiercely about people's time with everything else, so they must offer appealing and individual experiences to draw people's attention. Mixed reality is one possible means of doing that.

A good application for cultural travel sector must measure up to the expectations of the public. During both Futuristic History and MIRACLE projects user studies of pilot applications were carried out. Studies of the Luostarinmäki Adventure[1] yielded valuable information about what the future users may expect of the MR technology in museums and other cultural heritage sites. Combined with earlier visitor studies from various museums some general features can be outlined.

THREE TYPES OF MUSEUM VISITORS

The expectations of the public naturally vary from person to person, but three types of museum visitors can roughly be separated, according to surveys carried out by the Finnish Museum Association[2].

The first type *seeks a place for meditation and quieting down*, distant from our own time. Members of this group may visit the sites also on nostalgic bases. This group is usually not interested in using modern technology on site whatsoever. Creating MR content that would please this visitor type may be demanding if necessary at all.

The second type *visits museums to get information about history and the place or site*. Many people in this group are interested in using new technologies which may help them to increase their knowledge. The content in applications targeted at this group must first and foremost be informative.

The third and, according to surveys, biggest group is *looking for experiences*. Many members of this group are rather young and willing to use new technologies, also MR, to gain new experiences. They also expect that modern technologies are used at least at some extent to present the sites or museums they are visiting. The content aimed at this group must be entertaining but also informative since the group mainly values educative elements alongside the entertaining ones.

An individual museum visitor has usually at least some characteristics from all these types or groups, which must be taken into account when designing the applications. This suggests that a good application should be well-balanced between entertainment and education and its use should be voluntary. Perhaps in an ideal situation there might be several different types of applications available in a museum or a site from which the visitors could choose. Another possibility could be an application that could adapt the content to the preferences of the user.

MIXED REALITY AND HERITAGE ORGANIZATIONS

Currently, the heritage organizations are awakening to the fact that larger and larger groups of visitors think of them more as places where to experience new things and less as places of mere learning.[3] The communicative mission of the heritage organizations is still important but it must be adapted to the new expectations of the visitors. The heritage organizations, therefore, need tools to modernize their services and to engage their visitors in the process of knowing, which is now held as interactive and entertaining. The heritage sector has clearly shown its interest towards technologies like MR which can make the museum experience engaging, entertaining and informative. All these three features are in center of the discussion about the modern museum exhibition.

The question of the needs of the travel sector concerning the use of MR applications on cultural travel sites requires further research. The travel sector is very closely linked to the museum and cultural heritage sectors, which makes it important to study the possibilities of the MR technology also from its point of view. At this moment, however, it is possible to state that the travel sector, like the heritage organizations, conceive of producing experiences as its overriding aim. The help offered by MR and other technologies is widely recognized[4]. The concept of combining the historical content with commercial and other useful information in same applications has come up and seems promising.

Evidence exists that cultural heritage tourism has already gained from MR technology. [4, 6] MR may help to prevent degradation of historical sites and offers the tourists enjoyable and useful access to cultural heritage[7]. Major attractions such as the British Museum and the Louvre do offer MR applications to their customers.

OPPORTUNITIES OFFERED BY MIXED REALITY

MR can make abstract and invisible things comprehensible and concretize complex historical phenomena.

It is possible to combine digital objects and intangible heritage with tangible heritage (buildings, objects). The resulting MR solutions may help to prevent degradation of historical sites. For example, restricted spaces can be entered virtually, and mechanical functions of historical objects can be presented virtually instead of moving the objects physically.

MR can be a cost-efficient alternative for some traditional means used in museums, such as museum dramas and physical reconstructions.

In most cases MR doesn't have to compete with other means of communicating historical knowledge. MR can be used e.g. alongside traditional exhibitions and guided tours. MR and "real" objects are not options but they rather complement each other. The museums can choose the best means of representation for their purposes.

MR applications can be more entertaining than some more traditional means of communicating (historical) knowledge. Therefore, it might attract people who wouldn't usually visit museums or heritage sites, e.g. young adults.

One of the most remarkable aspects of the MR technology is its ability to offer information that would be very difficult, expensive or totally impossible to present with other media used in museum exhibitions and heritage sites. There is much information that cannot be presented or which is difficult to grasp in textual form[5]. Using other media, like images, may help in these cases but some pieces of information are inconceivable until they are presented in connection with the physical reality.

Combining information with the physical reality enables the visitors to use their own bodies as instruments of learning. This makes it easier for them to comprehend for example the physical scale, the spatial relations and the movements of the presented things. It can also increase the opportunities to learning by doing and empathic learning of the life in the past.

Enabling this with the help of MR was tested with positive results within the cases of the Luostarinmäki Adventure and the Louhisaari Stories. Elements added digitally to the view, like a demolished fence or 19th century seastrand made the whole environment more comprehensible. The possibility to interact with the environment and the characters in the Luostarinmäki Adventure and the feeling of actually being in the past caused by this possibility enhanced opportunities for empathic understanding of the past realities. The same idea of immersing people in the past was also the motivator behind the augmented SelfieWall pilot at Vellamo.

MR offers a relatively low-priced alternative to presenting history through museum theatre performances or re-enactments of past events. Digital characters representing people of past times with which it is possible to interact or communicate are more affordable than live actors although they hardly can entirely replace a real person. Using these characters can help the heritage organizations to solve one of the most paradoxical and challenging problems they have. Representing human life in the past is an important mission for the organizations and yet they have to do this only with the help of the material culture since the human beings are gone, and the past life itself exists no more. The MR technology enables bringing the people of the past to life, although as recreations and interpretations of researchers of our own time.

Various studies on learning have shown that people learn better by doing and by teaching others than by only reading or listening[6,3]. The learning results are the better the more senses can be involved. Using the whole body supports the learning process and helps memorizing the learned things.

WHAT RISKS ARE THERE?

Mixed reality technology can carry also some remarkable problems and even threats with it. Those responsible of creating mixed reality applications for cultural heritage and cultural travel sectors must be aware of these possible threats.

An essential point to note is that mixed reality—or any other technology—should not be used self-purposefully. It must earn its role by bringing in benefits that are unattainable with other media for representation and communication.

Until now, MR technology is being used at cultural heritage sites and museums in many cases mostly because of its novelty value and its WOW effect. Creating impressive experiences is easy because the technology itself is new to most of the visitors. There lies a risk that the technology takes the visitors' attention from the content. Even more disconcerting risk is that after the technology has lost its novelty value and ceased to attract visitors by its mere WOW effect it can be deemed worthless.

Examples of such cases can be found in history. 3D (stereoscopic) cinema had a brief period of success in the 1950s. A number of feature films were made, also by major studios and directors, and people went to see them wearing anaglyphic (red-cyan colored) glasses. After a while the novelty was gone, popularity ceased, and eventually making of 3D movies essentially ended. A new boom started in 2000s enabled by digital projectors and electronic shutter 3D glasses. It may be too early to judge whether stereoscopic movies will again go away, but the percentage of 3D movies from all movies seems to be declining. The WOW effect and novelty do not seem to be able to keep up against the problems: inconvenience of the glasses and side-effects like visual fatigue, nausea and headaches that many people suffer.[9]

These risks can be dealt with by choosing the technologies so that they really fit to the intended content, and by trying to avoid the known problems and utilize the technology as well as possible. Especially, it is very important to keep the content in center when designing the applications. The content alongside the medium of its presentation should be the source of the experiences, not the technology alone. The novelty value of the MR technology should not be relied upon as a visitor attractor since the technology is rapidly becoming more common and people learn to know it.

The current limitations of the technology and the capacity of the available equipment may create obstacles for presenting content which would otherwise be relevant. The technology needed to make something specific may still be a few years away, so it must be considered whether it is wise to wait still and perhaps make something else first.

There are also other practical risks (costs) that must be considered when planning a mixed reality service, such as:

How much updates and maintenance are expected to be needed, and are there enough resources (personnel, funding for subcontracting) for it?

If there are devices to be loaned to visitors, how much expenses would be spent for repair and stolen units? How can those costs be minimized?

How much help the visitors need in downloading the apps to their own devices and in using the apps? Is there enough personnel to take care of it?

THE ROLE OF SOCIAL MEDIA

Mixed reality technology can change the role of museums and other cultural heritage organizations in the communication between them and the public, although this is not an inevitable result of just taking the technology into use. Especially social media channels in connection with the MR technology could offer the public a possibility to take part in providing information in the museums. This is of course possible with the MR technology itself and even with the traditional exhibition methods, but it seems that the more modern technologies are involved the more open and reciprocal the content creation for exhibitions and for heritage sites will become. The technologies enable the heritage organizations to engage and involve the public and the museum visitors to make knowing into an interactive process in which all parties can learn and share information. This, in turn, would decrease the notion of the heritage organizations as authoritarian and excluding. Part of the authority to determine what can be counted as cultural heritage, what information about the past is significant and what is not can be passed from the organizations to the public[8]. Another question is, in what extent, if at all, museums should take this opportunity.

A modern trend, however, seems to be that heritage organizations use social media actively as a channel to provide their services. The public and the visitors have become aware of this and they expect to find the organizations in the social media. Using social media can make the heritage organizations more open, including and involving towards the public. The visitors want to share their museum experiences with their friends in social media and this comprises also the MR experiences.

People's willingness to share mixed reality experiences was inquired in several of the MIRACLE pilot cases. A questionnaire item "I would like to share my experience to my friends is social media (e.g. Facebook, Twitter or Instagram)" or an essentially similar one was included in the questionnaires for the road grader simulator, the 360 rally simulator, the optical telegraph, The Amos Anderson installation, the Sanan seppä, the Luostarinmäki adventure, the Transformations of the Knight's Hall and the Make Your Own Exhibition app. However, people did not seem to be keen to share their experiences in social media. The median answer for the statement, across all these cases, ranged from somewhat disagree to neither agree or disagree. This does not necessarily mean that the respondents would be against the idea of sharing such content in social media in general. Instead, one possible reason for this rather negative attitude might be that people do not see the traditional and obvious ways of sharing content in social media feasible for such installations. Thus, new and easy-to-use ways to share one's mixed reality experiences should be designed and tested.

Social media offers a promising tool also for crowdsourcing as a method for information gathering for the organizations and for sharing information between museum visitors. Using this in the content creation process for MR applications for heritage sites should be studied further.

VIRTUAL RECONSTRUCTIONS OF THE PAST

No matter what we might think, the material reality around us is mute. Even the most exciting vestiges of the past remain silent until we make them speak. We—the people living in the present—give them the words, which we then listen as if the objects themselves would be speaking.

We easily forget that the past itself is irretrievably lost. The old buildings we enter in hope for stepping back in time won't take us on a time travel. We can't see them as they used to be. They are worn by time or altered and renovated or both, and therefore look different than when they were new. They are solely part of the present. All what we can say and think about the past is created in the present and in our minds. It is our imagination that constitutes how we conceive the past.

Nevertheless, the material remains of the past form a link, however vague, between the past and the present. As knowledge about the past is constituted in the present, it is the material remains of the past, the objects and the archival sources, which provide at least a firm basis for this interpretative work of recreation and reconstruction. Because the material reality itself does not tell anything, it is crucial to develop methods to link the interpretations made about the past directly to the material remains of the past that have functioned as sources for the very interpretations. In other words it is important to provide visitors at a historical building or a heritage site with historical knowledge based on and concerning that site. It is noteworthy, that texts or language in general, may not be the best method to communicate this information. Currently, mixed reality (MR) technology is one of the most promising new methods for narrativizing material reality.

Especially narrative MR applications can be very useful in communicating historical knowledge to the public. MR technology can offer information and experiences that would be very difficult, even impossible to represent with traditional media used in museum exhibitions and heritage sites. All aspects of the past life are just not reducible to words, still images or other traditional means. Mixed reality can connect historical information with the material reality, making history visible in situ and thus make it more comprehensible.

As the case of Sanan seppä application suggests, one of the most significant aspects of MR is that it enables combining digital reconstructions and other additions, storytelling and historical knowledge directly with actual locations thus multiplying the information available for the people visiting the locations. The direct connection of the information to the material reality makes the interpretations easier to grasp. The multitude of different types of source material available improves the process even further. To understand a site or an object they see, visitors are not compelled to read an explaining text and then to translate the textual information into a visual language in their minds, but they can actually see, how these vestiges of the past have changed, how they were used etc.

Because all the additions are digital, the material reality remains unaltered. Using MR based on markerless tracking leaves the physical space intact. Neither is the amount of information available limited by the number of or space on information boards, since the boards themselves can be replaced with digital versions, in as many languages as required, or with more advanced methods of communicating information. Storytelling with the help of digital characters is one of these methods experimented in Sanan seppä application. In this case the chosen method of storytelling, i.e. using fictional characters, proved to be suitable for explaining the material reality of the Cathedral, the intangible heritage stemming from the days of the reformation, the length of the reformation process and the changes it brought to the society as well as varying meanings of the reformation for contemporaries.

One more advantage of the technology is, that presentations based on MR are available any time. They are not dependent on for example timetables of actors or live interpreters. These representations are also more cost efficient than many other methods, especially if the most part of the visitors download the application on their own devices, and the heritage site or the museum provides devices only to those missing suitable equipment for using the application.

The case example of Sanan seppä, however, indicated also some weaknesses in using MR in communicating cultural heritage. The most serious issues dealt with the current state of the production process. Since established practices for many phases of building an MR application such as Sanan seppä were missing, excessive amount of development work was needed to complete the application. On the other hand, the findings and solutions reached during the process will, for their part, improve the state of the MR production process.

As long as MR applications are used on tablet computers and smartphones, the users look their surroundings through camera view on a small screen. A risk exists that the users look their surroundings only through this screen and forget that what they see actually is around them, not only in the digital world opened up by the screen. The better and more engaging the content of the application, the greater is the danger. Paradoxically, making applications that present the cultural heritage too well may substitute the actual heritage with a digital version and prevent users from seeing the real heritage instead of the digital representation of it.

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2.4 MIXED REALITY IN PEDAGOGICAL USE

NARRATIVE AR APPLICATION SUPPLEMENTS CURRICULUM CONTENT

Augmented reality based technology can be used to produce different kind of experiences for supplementing elementary or high school level teaching and learning. One possible use of AR is to support and enhance educational visits to museums, churches and other cultural sites. These kind of visits are important part of many modern curriculum courses.

Newest curriculum plans in Finnish elementary and high school emphasize utilization of ICT in all subjects to create diverse learning environments. Curriculum plans encourage teachers to blend new forms of technological aids and out of the classroom -learning into teaching that is more conventional. Curriculum plans also value highly phenomena based, multidisciplinary and active learning. AR application used independently and actively by students and pupils as part of culture site excursion fits well to these requirements set by curriculum plans.

Sanan seppä AR-story, produced as part of MIRACLE-project, is a good example of application that can be used to supplement history, language or religion courses in elementary or high school level. It combines multidisciplinary content, dramatically expressive story and use of AR-technology. Application presents story of historical fiction set in different locations inside the Turku cathedral and utilizes AR as a tool of storytelling. User moves actively inside scenes played by virtual actors. Sanan seppä differs from more fact driven and formal spatial visualizations that educational AR often uses by trying to create engagement with historical story.

AR application telling an informative story is a special medium that can be blended with other forms of information to create more diverse and memorable presentation of subject. This mixing of ways of learning and medias to approach the subject matter fits well into the idea of blended learning. Constructivist and socio-constructivist learning theory view that information from many different sources contributes to individual's active construction of knowledge. These constructivist viewpoints are also present in currently popular idea of phenomena based learning.

Thoughtfully written screenplay for virtual actors can support phenomena based learning by providing lots of interesting content and details in different areas and knowledge levels. Story with high pedagogical quality offers something interesting for all. For example in Sanan seppä application elementary level student can view story in more concrete way focusing on differences between everyday life of 1600th century and present day, but more mature student can connect story's events neatly to larger historical context. One important demand for good educational AR story is to bind it strongly to its real location. Virtual characters can be aware of their real features of environment and direct users focus to make them more aware to his surroundings. Characters can even interact with real environment utilizing help of masking and virtual props.

Believable virtual actors that feel to be present in same space as user and exciting dramatization of otherwise distant historical time and events provide engaging learning experience. Inquiry made to students who tested Sanan seppä application showed that there was strong correlation between how interesting story was perceived, and how willingly it was used to learn about subject.

Combining narrative drama to more analytical and formal information can invigorate historical context of culture site and help to integrate it more efficiently to subject matter and curriculum content. In general, AR is efficient in creating feeling of presence with content it presents. Active spatial presence and engagement with events of historical distance is core element of narrative AR's educational strength.

In ideal situation user, incorporating AR story can create formidable and memorable experience. This feeling of presence is threatened if virtual content feels too much superimposed, stands out from real environment or if user is not able actively reposition himself in scene. This places requirement to smoothness of tracking and visual assets quality of embedment.

TOWARDS EXPERIMENTATION IN LEARNING

Research conducted by the MIRACLE evaluation consortium has shown the possibilities of AR in visualizing the invisible by projecting virtual objects onto real setting. Several different AR applications created by MIRACLE proved to allow physical "hands on" and intellectual "minds on" experimentation with instructional learning scenarios. According to pedagogical experts, museum professionals and teachers, the approach represents moving from teacher or museum guide controlled learning to pupil or visitor oriented learning. Usability, availability and price of AR technology are soon making it available for everyday education—the threshold seems no more to be money or technology, but mental resources.

In educational sector AR generally means a modern computer-assisted learning—environment that combines the observed real world phenomena with graphically added information or images, even spatially positioned sounds can be used. The meaning of augmented information is to enrich the original phenomenon by information that is useful in many kinds of revolutionary applications in education, including the study of architecture, art, anatomy, languages decoration, or any other subject in which a graphic, simulation or 3D model could improve comprehension. More concrete examples of using augmented reality are historical heritage reconstruction, training of operators of industrial processes, system maintenance or tourist visits to museums and other historic buildings. What is noteworthy relative to this study is the fact that the teaching applications of mixed and augmented reality are still minimal.

The fast development of new technologies and the effects of these in the society also change education. We believe more and more learning will happen in informal learning environments, i.e. outside classrooms, in the future. We learn better by doing than by reading and listening to a teacher. The wide variety of media available to everyone will help to learn better, and interactive applications are a further step towards better understanding of science, history, art, geography or nearly any form of knowledge. The need of producing such material is increasing at the same time as the capabilities of consumer ICT devices are growing.

People learn more in informal settings and open learning environments. In addition, all learning is based on motivation. The latest research literature has clearly indicated that augmented reality type of learning technologies can enhance the situational motivation into intrinsic motivation: e.g. real interest in new topic based on facts and deep-learning strategy both for young people and adults. This seem to be evident also in several MIRACLE case studies. People were learning also phenomenon in their leisure time, and also experimenting things that never exist in the official curriculums.

Lifelong learning needs new practical forms: the formal education can learn from the informal, open learning environments. The existing results indicate and encourage for further development of Augmented Reality educational solutions. Meaningful learning has two components. First, the content should be meaningful for the learner. Second, the learning process should be arranged pedagogically in a meaningful way (according to the age and the former knowledge and skills of the learner and by the logical structure of the topic.) All the great innovations in learning field have been based on putting these two principles into practice. MIRACLE was putting together the real physical environment and virtual experiences. One of the key elements is to bring together concrete objects and abstract phenomenon.

MIRACLE & THE 5-E MODEL

ENGAGEMENT

Object, event or question used to engage users and visitors. Connections facilitated between what visitors know and can do.

EXPLORATION

Objects and phenomena are explored. Hands-on activities, with guidance.

EXPLANATION

Visitors explain their understanding of concepts and processes. New concepts and skills are introduced as conceptual clarity and cohesion are sought.

ELABORATION

Activities allow learners to apply concepts in contexts, and build on or extend understanding and skill.

EVALUATION

AR-appliers assess their knowledge, skills and abilities. Activities permit evaluation of student development and lesson effectiveness.

REPORTED LEARNING RESULTS BY USING AR-SOLUTIONS

One indicator of the AR boom in education is that there have been several recent meta-analyses about the topic. A number of those are listed in the references section. In Radu's "Augmented reality in education: A meta-review and cross-media analysis"[5] AR solutions are compared to non-AR solutions. The positive outcomes of AR include increased content understanding, learning spatial structure and function, learning language associations (like the meaning of written words,[1]), retention in long-term memory, improved physical task performance and increased student motivation. On the other hand, the negative outcomes were as follows: attention tunneling (focusing attention to a particular channel of information, which might to lead to neglect of relevant events on other channels,[2]), usability difficulties, ineffective classroom integration and learner differences.

The 5E-model suits very well as the pedagogical framework for MIRACLE Augmented Reality approach.

Authenticity of science learning[3] has been found to be an effective motivating factor. AR educational solutions have been trying to use it as the starting point while designing AR simulations. In a study[4] related to role playing by AR, the topic to be learned was disease transmission that the students could affect through their own actions. According to the results this kind of 'participatory reality' game has made new kinds of authentic science inquiry experiences possible. This approach has become known globally during the Pokémon GO game trend in 2016.

THE MAIN RESULTS BY INFORMAL VISITORS

- Augmented Reality advances the learning especially in informal science education context.
- Making the invisible observable is possible by Augmented Reality. It gives several opportunities to learn highly abstract things in a concrete manner.
- The MIRACLE results showed that AR-technology experience was beneficial especially for the pupils, who otherwise belong to the lowest achieving school success group. They were reaching up the gap with other students while learning science. On the other hand, the students with the high-performance school success gained more challenge and quality for the learning outcomes.
- Video games and computer based entertainment and serious pc-educational games have traditionally been more beneficial for the boys. However, in this MIRACLE-case there was no gap between boys and girls in post-knowledge testing; thus the girls benefitted more from the informal learning experience than the boys.
- Girls had a higher relative autonomy experience (RAI) as an important background factor for high-performance learning.
- Meanwhile, situation motivation was much more strongly inter-connected among the boys.
- AR seems to be also a good tool for different learners. It is bridging the gap between formal education and informal learning in an effective way.

RESULTS OF TEACHER BY TEACHER EXPERIENCES

- Moving from a teacher-controlled learning environment towards a pupil-orientated learning one.
- Connecting MIRACLE & AR with and between learning environments.
- Seeing remarkable changes in the roles and responsibilities of students and teachers towards student centeredness, autonomy, and peer collaboration.
- Teachers were also seeing structural changes in the learning environments.
- It gives several options for utilising the phenomena-based-pedagogy outspoken in the new National Curriculum 2016 of Finland.

The question related to the museums, exhibitions, science centres, and other informal leisure time activities is whether they are capable of managing to orient and enhance the momentary, strong situational motivation into a long-lasting intrinsic motivation. This is also one of the biggest challenges for open learning environments, such as the topics of MIRACLE.

Radu[5] names two weaknesses of using AR in education: a) ineffective classroom integration and b) learner differences. But, actually, we use the re-framing approach[6] to change the 'weaknesses' into strengths. The 'ineffective classroom integration' gives the opportunity for especially out-of-school methods to bridge the gap between formal education and informal learning via AR. Also, the 'learner differences' is also an important factor. MIRACLE/AR clearly offers new types of learning paths for different types of pupils. Augmented Reality seems according the MIRACLE experiences to be turning out to be one of the very few and rare pedagogical solutions that benefits those pupils who are below average in traditional school success and achievement level.

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2.5 BUSINESS ASPECTS OF CULTURE-ORIENTED MIXED REALITY

MUSEUMS AND CULTURAL HERITAGE SITES AS CLIENTS

Mixed Reality experiences in Cultural travel sector will most likely to become profitable business for enterprises in near future. Currently, there is already a growing need for companies producing applications that can provide cultural travellers with both experiences and information about cultural heritage sites. To be able to answer this need and to deliver their products on a reasonable price, companies require information about 1) needs and purchasing habits of the Museums and other Cultural Heritage (CH) sites, 2) cost efficient production workflow which involves collaboration and co-creation with both customers and other stakeholders and 3) the needs of the end users of the applications

Museums and cultural travel sites have their special characteristics which must be taken into account when considering offering MR solutions and technologies. Many of the sites and organizations today are trying to cope with especially decreasing public funding. This has made them aware of the need to raise additional income, even from commercial activities. As a result, the field has been divided. On one hand are those who stress that museums and other agents on the field must respond to the consumer-led society and provide more what visitors want. On the other hand are the critics accusing the organizations of oversimplifications and preferring entertainment to education.

Paradoxically, at the same time the reducing public funding has made the field commercially more involved, it also has made the field more unwilling to take any risks. Adapting too novel technologies or business models not tested elsewhere might seem like waste of already scarce resources. The possibilities of activating new visitor groups or gaining more income are not viewed as results alluring enough or worth the risk.

Furthermore, even the commercialism itself is a controversial notion within the cultural travel sector. Consisting mostly of non-profit organizations the sector has only gradually awakened to the realization that strive towards profitability, at some extent at least, might be unavoidable for maintaining their activity.

MR for museums and cultural heritage sites offer another content layer in the overall experience. The MR therefore is a gamified or otherwise digitalised level of the experience, an experience which itself and even without the MR has gathered the audience. Hence the MR experience is not be-all-end-all solution but only an augmentation of that what already is and should be considered as such. This can generate additional visitors to a museum or cultural heritage site, but the delivery method for acquiring the best cost-benefit ratio is yet under research and thus the business model is important in finding the optimal method.

CREATING THE DEMAND

Augmented and mixed reality is used to make museum visit more interesting and engaging to visitors. However, the applications currently available are primarily individual and expensive productions.

When offering MR solutions to museums, the key question is how to convince the customer how MR helps the museums to make their collections and cultural heritage in general more accessible and engaging to visitors by using interactive digital content. Referring to the usability study results (e.g. publications of MIRACLE project) can be of great help. In addition, the museum experts need to be convinced that MR also creates new co-creation possibilities for cooperation of cultural heritage professionals, historians and technology researchers. In addition, this technology develops profoundly new ways for curating exhibitions.

The key issue in getting the customer interested is how the supplier can communicate mixed reality in its various forms as a new genre that will interest audiences, and that its possibilities are growing constantly as the development of the technology proceeds. Mixed reality can successfully compete with the traditional storytelling and exhibition techniques, including relatively modern tools like multimedia. MR is versatile, interactive and new, so it can offer more than the traditional tools. However, it is important to ensure that the quality of content is kept high. Even minor problems can spoil the entire experience.

The ways of obtaining information are changing rapidly in the modern society. Curiosity and will to learn new things have all but diminished; they only have taken another form. Text is losing ground to other media, such as different types of multimedia. Mixed reality can answer to these needs. Combining physical and digital environments gives new opportunities to learning experiences that would not be possible without mixed reality.

CO-CREATION OF THE MR EXPERIENCE

When done correctly, the fields of history, museology and cultural tourism will all benefit from MR technology as a new medium for communication between history experts and their audience. It can improve the user experience, accessibility and the way pedagogy in museums, archives, libraries etc. is conducted

The emerging 'MR industry' includes new roles for existing actors. It can be visualized by locating actors with different roles into a value-network, visualized in image 1.

In the value network, new innovation capacity for Cultural travel not only emerges, but also converts into actual business between stakeholders in cultural heritage sector and local SMEs. While planning and building the MR applications in MIRACLE project, we identified local networks of culture and media enterprises suitable for an active role in MR business and involved relevant companies to creation of the applications as contractors. Managing the supply and production together with other actors and understanding both needs and purchasing behaviour of Museums and Cultural heritage sites will be essential for these companies for accessing this market.

In order to ensure cost-efficient production of MR applications, the knowledge and content creation process has to be streamlined, and the development and authoring tool support has to be good enough. As the museums are often already employing researchers, curators and other relevant personnel, the museum staff can already produce content for the MR applications that are part of exhibitions—if they only have such tools that are easy to use. Therefore, the need for technical development work requiring deep technological knowledge has to be minimized and could be outsourced to local SME's. In addition, there might be a need to develop completely new authoring tools that are targeted directly for the museum staff. Some enterprises can concentrate in making the applications, creating content and running the services, while some

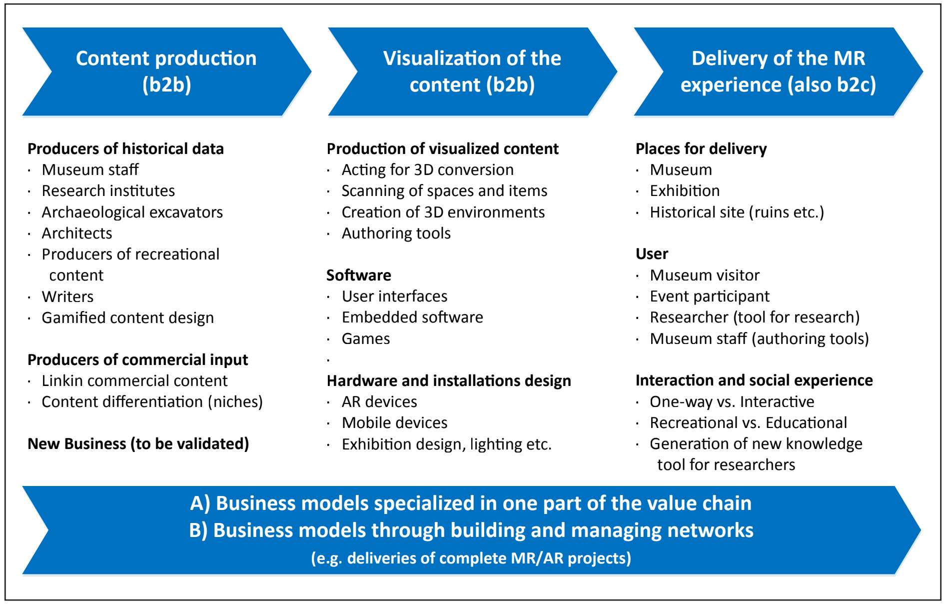

Image 1: Value network for Cultural Mixed Reality Applications

others may develop the tools and methods and make business selling them. This process is referred as the MR contents value chain and it includes actors from content creation, visualization and delivery.

PRICING AND BUSINESS MODEL

When making business model and pricing decisions, it has to be taken into account in which ways museums organise their funding. In some cases, museums will get a specific, project-type, budget for building an exhibition. Regardless of whether this kind of funding comes from a sponsor or from the museum itself, it will be more or less a lump sum and has to be enough for almost everything related to the exhibition. In this scenario, the customer should be offered MR services with one fixed price, including the upkeep of the application. If any extra costs will occur later, the customer may face difficulties in finding the missing financial resources. This is also the case with upkeep and service functions—they have to be included in the price.

If, on the other hand, the customer runs the exhibitions and other activities on yearly budget, large investments in exhibition technology can be difficult to justify. This can be the case with permanent exhibitions and infrastructure. In these cases we encourage providers to suggest pay-per-month pricing for whole upkeep. This not only lowers the purchasing threshold but it also brings constant cash flow often important for a small company.

It is notable, that museums operate with both project-type and yearly budgets. This means that the provider of an MR service needs to be ready for offering the content to be purchased in both ways.

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2.6 CO-OPERATION IN MULTIDISCIPLINARY FIELD

KNOWLEDGE AND SKILLS REQUIRED TO CREATE AND MAINTAIN MR APPLICATIONS

Experiences gained during the Futuristic History and MIRACLE projects indicate that creating MR applications for cultural heritage sites in current state of technical development requires cooperation between experts of various sectors. It is improbable that the situation will change dramatically in next few years. Using the available platforms, software and tools for application building and content creation demands familiarity with the technology and special expertise that curators and other museum staff currently cannot be expected to possess. On the other hand, IT specialists may not have sufficient understanding of museological basic principles or museum pedagogy and they need more fundamental assistance than delivering mere historical facts in designing the applications. In addition, involving various other sectors in the process is highly advisable.

The most important specialists to be included in projects involving creation of MR applications for cultural heritage sites are curators and various types of IT specialists like programmers and 3D modelers. The curators have the expertise on the historical facts and they usually have the clearest vision of what is suitable and desirable for the museums and the organizations they represent. The IT specialists have the needed technological skills the museum personnel may lack and they should have adequate experience in creating similar applications. Representing typically companies or enterprises, they may work on clearly different conditions than the museum staff, a fact of which the latter should be aware of.

Besides these two main groups a few other sectors may have significant benefits to offer. Researchers of history at universities have knowledge on current trends and latest research results of research of history. Usually their point of view differs at some extent from that of curators in heritage organizations. Therefore, it could be fruitful to enable the conversation between these two groups when designing the historical content and the stories to be told in and with the applications to be created. Involving scriptwriters could also be extremely useful for creating a good and engaging story.

The visual image of an application is extremely important in making it appealing for the users. Therefore it might be worthwhile to have also people with artistic expertise involved. Cultural heritage sites are closely linked to travel sector since travelers are along with school classes the most important visitor group at the sites. The expertise of the travel sector is required to answer to the needs of the travelers. School teachers again are the best to advice on how to connect the content in the applications with the school curriculum. Marketing experts on the other hand could be consulted on how to amalgamate commercial information with the applications in a discrete way.

It must be kept in mind that the required amount of cooperation between different sectors varies remarkably from application type to another. Creating technically simple small scale MR applications does not necessarily require any additional experts as the needed expertise can be found in the heritage organizations. The more complex the technology used is the more IT specialists will be needed and the more probably the work should be assigned to an enterprise with experience of similar processes. The more diverse the desired historical content is the more historians outside the heritage sector should be involved. The higher the commercial or attraction potential of the application is estimated to be, the more experts from tourism and marketing sectors should take part in designing them. It is essential to assess the required size and composition of the team for application creation in advance.

One interesting aspect is the possibility to simplify the creation and maintenance processes of cultural heritage applications so that heritage organizations could insert the content they have produced directly to the application platform without any outside technical support.

TAKING ALL SKILLS INTO USE

The historians, curators and other members of the heritage organizations are experts on the historical knowledge, which should be in center in every application created for cultural heritage sector. Members of the museum staff and the cultural heritage organizations have the best knowledge of the principles on which presenting the past is based in their organizations. Historians on the other hand might be better aware of the various aspects in history which could be presented in a particular site with the help of the MR technology.

The amount of work needed from historians and curators depends on how much suitable material there is available for the content creation. It must be stressed that textual material needs more processing than images or objects to be fitting for the content creation, since the applications present the historical information mainly in visual form. The role of language in mediating the museum experience is smaller than in traditional exhibitions or when the historical knowledge is published as books or articles. Converting the existing historical research (published in textual form) into images and finding suitable visuals for the purposes of the content creation will demand time. This must be taken into account in budgeting time and resources for this kind of a project.

Besides the historical knowledge and the knowledge of the principles of presentation adapted by the heritage organizations the historians and curators can be expected to possess some other expertise that might be useful in creating MR applications for heritage sites. Usually even the smaller museums have personnel with IT skills beyond the basic level. These skills are becoming more common also among researchers of history at universities. The heritage organizations have also strong expertise on museum pedagogy and the educational potential of the heritage sites and museums. The large organizations and museums usually have specialists of for example marketing and legal issues. These institutions have the strongest changes of getting by the building of small scale MR applications with their own human resources. The smaller a museum or organization is the more probably it will need help from several sectors and enterprises.

ORGANIZING THE CO-OPERATION

The pilot application projects have shown that it is most useful if all the experts taking part in application development would have the basic knowledge also of the other sectors involved in the project. This is essential for making the cooperation fluent and for avoiding waste of time caused by misunderstandings. Learning to understand working methods, mindsets, values and the basic vocabulary of the other sectors is more important for functioning cooperation than learning mere facts like names and years, or using of particular computer programs.

The best way to learn to work together is to work together. The learning process will, however, be more fruitful if some time is reserved for it in the beginning of the project and if emphasis is put on explaining working methods, values etc. of the different sectors. This became clear during the creation of the Holy Ghost Church application in the beginning of the Futuristic History project. The cooperation between the different branches involved in the project became more effective after the researchers were able to understand each other's ways of thinking, without necessarily knowing much about even the basic facts of the other sectors at that point.

The basic rule for efficient distribution of work is naturally that all specialists involved concentrate on their own sectors of expertise. This rule must be supplemented with the notion that the experts should also pose questions to the other specialists about the aspects and facts they consider unclear. These questions may help the specialists to understand which of the things they hold self-evident need to be explained and justified more clearly.

Those involved should also express clearly what they need from the other experts. In practice this means that for example the 3D modelers should describe in detail what kind of reference images they need from the heritage organizations or the historians. Also the organizations commissioning an application must keep in mind that without proper instructions the enterprises or IT specialists responsible for building the application cannot work as efficiently as possible.

Constant communication between the different disciplines and sectors is one of the most important factories for efficient and successful process. There should be at least one specialist of each involved sector to be consulted during the whole process. It is difficult to organize the work in succeeding sequences so that specialists of each sector would be needed only a short period of time. On the other hand it is obvious that all the people involved cannot be and are not needed to be working full time during the entire process. There will be more intensive periods and periods when only some assistance will be required. This means that within the heritage organizations as well as in the enterprises the participation in individual application creation processes should be integrated as part of the duties of the employees involved.

3. PRODUCTION GUIDELINES

This chapter describes technologies and processes that are needed in the production of MR applications. Guidelines are given about choosing suitable methods and tools for different cases. Main focus areas are storytelling, scripting and visual content creation.

3.1 SOFTWARE AND HARDWARE PLATFORMS

SOFTWARE

There are several types of software platforms and frameworks that can be applied to creation of mixed reality experiences. Which ones to choose depends on the case and intended uses. Some of the currently available, relatively popular options are briefly described here.

RICH CONTENT CREATION & DEVELOPMENT PLATFORMS

Unity[1] and *Unreal Engine*[2] are two widely used 3D game engines. Both of them consist of a wide range of tools for building 3D games—or other applications—and deploying them on the common platforms, including Windows, Mac, Android and iOS. Although intended originally for game development, and especially games in 3D virtual environments, these development engines can also be used for making mixed reality experiences. Both have a plugin framework that allows adding many kinds of tools and extensions to the system, and typically other separate tools are used in projects to make content.

In June 2017, i.e. after the MIRACLE project, *Apple* published the *ARKit* platform[3] for iOS 11. It is a framework for creating augmented reality experiences for Apple's mobile devices, iPhones and iPads. ARKit is a result of Apple's 2015 acquisition of Metaio and other technology companies, and developing their solutions into a complete platform. ARKit is expected to have a major effect in bringing AR into wide use in consumer devices and in many application areas.

ARKit uses camera data—from both front and back cameras—and motion sensor data for tracking. It can find horizontal planes, like tables and floors, where virtual objects may be placed, and it can also estimate the lighting in a scene and apply simulated light and shadows to virtual objects.

ARKit runs on Apple's high-end processors (A9 and A10) that are found on latest product generations, and the iOS 11 operating system to be released in the fall 2017. Currently it seems to be an Apple proprietary platform running on Apple hardware only and not on other mobile platforms.

AR CREATION AND PRESENTATION SOLUTIONS

There are numerous providers of AR browsers and mixed reality development systems. Many of those are consumer-oriented in the sense that content creation does not require much training or traditional software development skills. Some examples of those are briefly presented below. A more extensive list of current (and also some inactive) MR solutions can be found in the MR database[4] made by University of Turku within the MARIN2 project[5].

- *Arilyn*[6] is a Finland-based company that offers a traditional AR-browser and Content Management System (Arilyn Manager) combo. Arilyn supports Android and iOS.
- *Layar*[7] includes an application, a creator and an SDK. The creator is a drag and drop -style editor, which allows users to easily create AR content for the Layar app. The app itself can be used to view all AR content created with the creator. Layar also provides services for creating custom tailored AR applications. Android and iOS are supported platforms.
- *Wikitude*[8] is an augmented reality solution that supports a wide range of tracking technologies and many AR devices, including see-through glasses. Wikitude Studio is an easy-to use tool included in the system, allowing AR content creation without programming skills. Also professional software development frameworks such as Cordova, Titanium and Xamarin can be used with Wikitude.
- *ALVAR*[9] is an AR/VR software library and development platform developed by VTT, Finland. It offers both marker-based and markerless visual tracking

technologies, and it was used in several of the pilot cases in MIRACLE.

- *Vuforia*[10] is a development platform for mobile AR. It can recognize many types of objects, like photographic images, markers, text, boxes, cylinders and other 3D objects, to be used as anchors for positioning the virtual content.
- *ARToolKit*[11] is an open source tracking and recognition SDK for augmented reality application development. Android, iOS, macOS and Linux are supported target platforms, and the license allows both non-commercial and commercial use.

VISUAL CONTENT SHARING

Many kinds of public services exist for sharing and distributing visual content.

- *Sketchfab*[12] is a site with lots of shared 3D and VR visual content, covering all kinds of subject areas from cultural heritage and art to technology.
- *Destinations* VR application[13] by Valve enables creation, sharing and exploring different worlds in VR: photogrammetry scenes, game worlds, or anything else that can be represented by a 3D model. The virtual worlds can be explored with VR glasses, and it is fairly straightforward to create new destinations using phtogrammetry.

HARDWARE

A viable approach to offering AR for the public is to make it work on common devices that people carry with them everywhere, all the time: smartphones and tablets. Many current devices are powerful enough and equipped with necessary sensors (camera, inertial and gyroscopic sensors, GPS) to run even fairly complex augmented reality applications. Capabilities for movement sensing depend on the built-in sensors and software, and devices on the lowest price categories may fail to run demanding apps, so it may be necessary to set some system requirements to target devices, and perhaps make a list of recommended devices. It is an important decision where to draw the line for performance requirements, i.e. what kind of compromise to make between how sophisticated the application is and how large percentage of consumers' devices can run it.

It is also possible to design the application to be run on dedicated augmented reality or virtual reality devices. There are many types with varying features, and more products are introduced all the time. Many AR and VR glasses at the moment are tethered, i.e. connected to a host computer by a wire. It can be assumed that new products in the future will be either wireless or fully standalone.

This is a selection of commonly known products as of spring 2017.

Augmented Reality

- *Microsoft HoloLens*[14]: standalone augmented reality glasses with high quality tracking of the surroundings. Can be controlled with hand gestures or simple hand controllers.
- *Meta2*[15]: tethered see-through augmented reality glasses.
- *Daqri Smart Helmet*[16]: helmet with standalone AR glasses. Daqri makes also smart glasses with a small computing unit, sensors and HUD technology.
- *ODG*[17]: standalone, integrated AR smart glasses
- *Google Tango*[18]: A technology platform enabling AR experiences with smartphones and tablets. Tango enabled devices have sensors for accurate motion tracking and area learning enabling a wide range of applications to be run.

Desktop Virtual Reality

- *HTC Vive*[19]: outside in tracking VR mask and dedicated hand controllers.
- *Oculus Rift*[20]: outside in tracking VR mask, Oculus Touch hand controllers can be added.

HTC Vive and Oculus Rift are similar products with offer a nearly full field of vision for the user, possibility of free moving within a limited area, and a good impression of "being there" in a virtual environment.

- *Microsoft*[21] has a *mixed reality platform* on which different manufacturers have announced products. These are also 3D headsets that occlude the user's natural view and are tethered to a computer.

TERMINOLOGY

inside out tracking: the device has sensors scanning the surroundings
outside in tracking: cameras/sensors are set around the usage area, tracking the movements of the mask and controllers
rotational: the device has sensors for rotational movements, but linear movements of the device/user are not (accurately) tracked
standalone: does not need a connected computer, all processing is done in the device itself
tethered: the device is connected to a computer with a wire

Mobile Virtual Reality

A popular type of mobile VR products are the simple head-worn masks where a smartphone is used as a display and computing unit. Rotational sensors are used to track the user's head movements.

- *DayDream*[22]: Google's VR mask, supports a simple hand controller.
- *GearVR*[23]: Samsung and Oculus branded VR mask with a hand controller support, to be used with a Galaxy smartphone.
- *Google Cardboard*[24] is a simple cardboard mask with lenses, having the same idea of using a smartphone as the computing and display device. However, there are no additional hand controllers or electric connections between the viewer mask and phone, so the viewer can be extremely simple and cheap, and many phone models can be used. The concept has been copied by many since Google introduced it. It has been applied in marketing campaigns, as it is possible to distribute a cardboard viewer even as part of product packaging with minimal cost.

Controllers

- *HTC Vive* Controllers & Trackers are part of the base system.
- *Oculus Touch* hand controllers are supported in the Oculus Rift platform but (so far) sold as separate products.
- *LeapMotion*[25] produces desktop and laptop hand controllers sensing the user's hand movements.

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3.2 TRACKING

In order to correctly align virtual objects with the physical world, Augmented Reality requires finding out the user's exact position and viewing direction (also known as the pose), and then keeping track of the movements. In practice this is equal to tracking the viewing device's camera pose. Several methods are available for the tracking task. It is application-dependent which methods are actually suitable: for some cases the positioning requirements can be fairly loose, while others require location data with a few millimeter accuracy. In a changing environment the system must be able to adapt to the situation while the application is running.

TRACKING TECHNOLOGIES

Sensors, e.g. **gyro-compass** combined with **GPS** (outdoors) or some other location-finding system (e.g., **WiFi** indoors) enables to track the device's pose within some accuracy; however the jitter and drift are typically too disturbing to enable high accuracy applications.

Outside-in camera tracking means tracking of the device with externally positioned cameras, LEDs, lasers or other e.g. magnetic sensors. This works only in limited spaces and requires special implementations. This approach is used for example in HTC Vive and Oculus Rift headsets.

Marker based tracking, typically using black&white matrix shaped patterns, placed in known locations in the environment, enables accurate and reliable tracking. The input data from a mobile device's camera is analyzed in nearly real time and searched for the known image. When the marker is recognized, the relative position of the camera can be calculated from the projection of the marker, and then it is finally possible to place virtual content over the input video. However, there are limitations with the operating range, and in many environments the markers may be considered aesthetically too disturbing.

Image based tracking, using nice-looking color images instead of b/w markers; this works well for many close range applications, but the operating distance is even more restricted than with markers.

Instead of 2D surface based positioning, it is also possible to use three-dimensional objects as positioning references. The term **"markerless tracking"** means using existing objects in an environment for tracking, so that there is no need to attach dedicated prints for this purpose. A recent approach is to capture the features of a known object in 3D space as a "point cloud".

Point cloud based tracking, based on 3D point clouds and features sets enables tracking of complex and also distant targets. The point clouds are typically created from several photos of the target, using third party tools such as *Agisoft PhotoScan*[1]. Main problems are found with managing of different viewing distances, lighting conditions and changes in the environment.

SLAM, simultaneous localization and mapping, works simi-

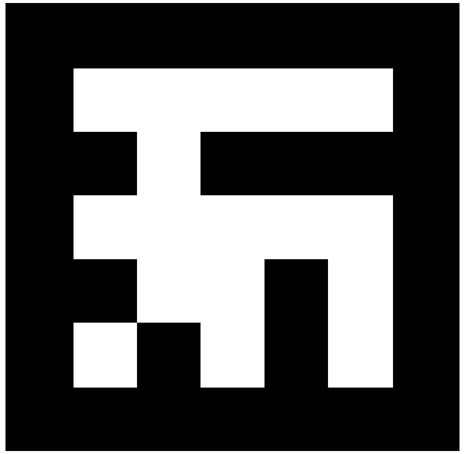

Image 1. A typical tracking marker.

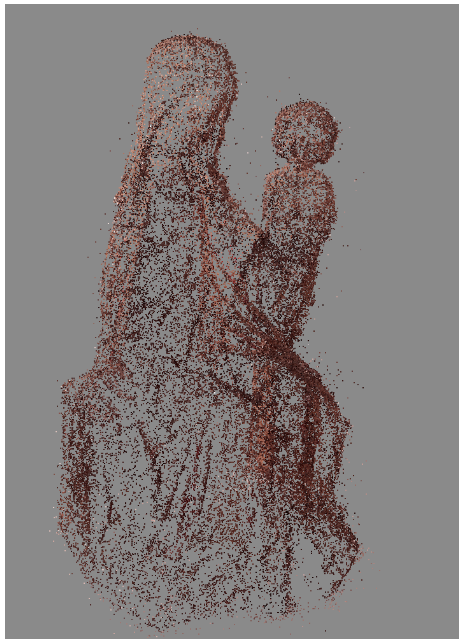

Image 2. Example of a point cloud.

larly to point cloud based tracking, but creating the point clouds by real time scanning of the environment instead of pre processed point clouds. The main downside is the need for a separate initialization step.

TRACKING PLATFORMS

Mixed reality platforms such as the ones presented in the previous section include one or more supported tracking technologies. Marker based, image based and point cloud based tracking options are common. The SLAM approach is typically used by depth camera based solutions. *Google Tango*[2] and *Microsoft HoloLens*[3] are examples of platforms using those.

Within the MIRACLE project VTT's *ALVAR*[4] library and its point cloud based tracking was used in many pilot cases, and the technology was also developed further during the project. Some technical comparisons were carried out, concluding that ALVAR provided the best performance especially for 3D point cloud based tracking , being strong on 2D marker and image based tracking as well.

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3.3 STORYTELLING

To offer informative and entertaining mixed reality experiences, instead of just showroom toys, the main effort must be put into the actual story. Historical and/or educational content must be in focus when designing the application. The form and content of the application must be coherent, but the technical implementation and form of the application and means of representation should be chosen to serve the purposes of the historical content, not on the contrary. Even narrative and entertaining applications containing fictional elements can (and should) be informative and educational.

SCRIPT WRITING

When there is a story to be told, it should be told well. A good story is at least as important as flawless implementation of an app. A professional scriptwriter may even be the best place to spend money in the project.

A complete story with a beginning and an end is not always needed. The experience may consist of more or less independent pieces that can be browsed in any order, or the user may only pick some of them. Whatever the pieces are, they should have an interesting experience to give to the user. If there are human characters, dialog with them is expected. Non-human objects should also allow the user to make a contact with them. They may be moved, modified or just observed, and there should be stories about them that give the user something to think.

SCRIPTING TOOLS

articy:draft[1] is a scripting tool that has been used in our productions. It offers the necessary functions for writing game scripts where the story may branch into several different paths depending on the choices of the user.

The user interface in *articy:draft* is simple enough to be learned in a few hours or days. It is thus beneficial to learn a tool like this if it saves more than a couple of workdays in the production time. We think this kind of tool is useful at least in games and other stories that have variations in the story. If the content is linear, with no variations, as is the case with traditional plays, a scripting tool may not offer much extra efficiency—at least if the author is not familiar with it in advance.

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3.4 CONTENT CREATION

In principle, augmented (virtual) content can be an artificial stimulus to any human sense, whether visual, auditive, tactile (touch), olfactory (smell) or flavor. However, most common is visual content that is produced and displayed by digital devices. Visual content may be two-dimensional—photographs, texts and graphics—or three-dimensional, and it may or may not be animated.

The skills required to make AR content are very much application dependent. First, expertise in the subject matter is needed. Second, the story and application design must be of high quality to keep user's interest in the subject up, and to prevent frustrations due to technical or other problems in the experience. Third, the making of the application and its elements may require specific artistic and technical skills, again dependent of the case. All these requirements are discussed in more detail in the following sections.

COMBINING DIFFERENT EXPERTISES

Content creation often requires expertise as well in the subject matter (like history, architecture, art etc.) as in the production tools (modeling, visualization, animation, interaction design etc.). Usually one person is not an expert in both of these, so it must be estimated whether it is more efficient to educate a substance expert to use the necessary tools, or to educate a tools expert about the substance facts, or to have one of both working as a team to produce the content.

As a general rule, it can be stated that when the amount of content to be created is small, it is efficient to create it by teamwork of the two (or more) experts. The more there is material to be created, the more efficient it becomes to train either the substance expert to use the production tools, or the tools expert to master the subject matter.

In most cases it is probably easier for substance experts to learn some specific production tools than vice versa. In our Sanan seppä case, for example, a historian learned to use the clothes modeling software Marvelous Designer[1]. It took a few days to be productive with it, whereas it can be estimated that the time needed for someone to get a sufficient level of knowledge about late medieval clothing would have taken a significantly longer time. Even the historian in question, whose fields of expertise didn't include historical clothes, 16th century or sewing, found it much easier and less time-consuming to learn to use the modeling software than to gather in-depth knowledge of 16th century clothing. (If the task would have been to model e.g. early 20th century clothes, it could have been vice versa, though. This is because there would have been considerably more visual information about clothing of the ordinary people and original patterns to use.)

To be successful with this approach, two things are required: the person should have the knowledge and skills to design the wanted things, like clothes, and there should be a tool that is easy enough to learn and capable of producing useful data for the application.

The first condition is likely to be fulfilled especially when we are talking about large units, like national or provincial museums. They often have many employees with different kinds of expertise, including researchers and other personnel who probably have necessary skills. (For example experts on clothing could be textile conservators, archeologists, researchers who are specialized in clothing collections and even seamstresses).

The second condition is heavily dependent of the specific area of production. Clothes design is an example of a task for which a suitable tool could be found. However, there may be tasks for which no such tool can be found—either the tools may be too complex to be learned in reasonable time, or the task is so specific that a tool hasn't been made at all, or isn't openly available. In such cases the way to proceed is to hire a professional who can do the task and perhaps make the needed tools.

VISUAL CONTENT CREATION

There are different ways of visual content creation. Choosing the most suitable one depends on what kind of experience is wanted and what are the resources and budget available for the project. Visual content can be based on 3D modelled virtual objects; this allows observing the objects from any angle, and the user may be able to move freely in the area where the content is to be displayed. In case the main objective is to display an existing environment but there is no requirement for interactive content, 360 degree video or photography may be an option. It allows just observing the environment—towards any direction—from one point at a time, but making such presentations is much cheaper than creating actual 3D content. These two methods are explained in detail in the following sections.

3D CONTENT CREATION

Making—or purchasing—virtual 3D content may take a major part of the resources of an AR or VR production.

Especially creating high-quality human/animal characters requires highly skilled designers, and even then the amount of time required may be significant. Therefore, an important part of the production process is to plan what content is actually needed and what is the best way overall to get it—purchasing, subcontracting, making it in the project, or going some other way? The cost issues related to 3D content creation may eventually affect also the choice of the overall concept: what kind of story should we have, how many characters to include in it, what kind of visual style should they have, and so on.

When budget is limited and compromises are needed, you can consider the following:

- **Can the plan be some way reshaped?** Has it too wide a scope, has it too many competing things that detract from the greater whole—in other words, can the amount of content be scaled down? Would it be worse, as good or even better? Cutting unnecessary stuff might make the result more focused.
- **What is good enough for this project,** would less polished assets fit the needs just as well? Typically, consistent look is aesthetically more important than having something very polished and something quite raw in same piece.
- **Can the look be simplified and made easier to execute?** Maybe it's not important to be realistic.
- **Can ready-made assets be bought instead of making new ones?** Maybe it's not that important to have a production specific style. At least having such ready-made assets at the start allows fast prototyping right at the beginning.

Existing or outsourced characters can be taken as the starting point, and by reusing and modifying them the workload can be reduced. Non-professional designers can be trained to model simple objects, and to modify existing objects in order to produce new object variants.

Photogrammetry and laser scanning

Photogrammetry is a potentially more economical way of producing virtual versions of 3D objects and spaces than manually modelling them. Photogrammetry means automated composing of a 3D model using a large number of ordinary photographs as the input data. Typically some tens or hundreds of photos taken from different angles and distances from the target are fed to a program that compares the photos, finds corresponding points and finally calculates a 3D presentation of the target. Agisoft PhotoScan[2] is an example of such software, also used in the MIRACLE project. Learning photogrammetry techniques does not require extensive training, so it is not always necessary to hire professionals for the job.

Laser scanning is another option for creating 3D models of existing objects. Scanner uses a laser beam to measure the distance from the scanner to every point in the target, and the resulting data is then converted to a 3D model.

Both photogrammetry and laser

scanning are useful for modeling static, solid objects, whereas living characters or shape-changing objects require other techniques. Photogrammetry does not require special hardware, whereas laser scanners are quite rare and expensive devices, usually not worth purchasing for occasional projects.

It is worth noting that to make 3D modeled objects appear natural, and to make them work in the mobile application, may require modifications to some objects, instead of using completely accurate models. The first issue is that if modeled strictly in the authentic scale, some things may appear too small in the application, so it may be better to exaggerate some parts or things. The other thing is that complex objects may require too much processing power to play well in common mobile devices, so simplifying may be needed. Such compromises require cooperation between application designers, technology experts and the experts of the subject matter.

In case of augmented reality projects, where something is to be added into an existing space, creating a photogrammetry or 3D scanned model in addition to accurate measurements is very helpful. This allows the artist to use and even examine the possibly historical space on her workstation for hints and markers about where long-lost structures have been and where their AR recreations should go. Such model also provides a virtual reference to historians on the project and allows for fast commentary regarding the authenticity of added constructs.

It should be noted that the project complexity may not be visible from the start, for example it might be challenging to estimate asset-heavy production times, as pipeline construction, testing and asset automation all may reveal unseen problems. This also happens because people may be optimistic about new project and thus commonly underestimate the workload. Therefore, it is recommended to test the asset creation time and, if needed, adapt the plan to fit what is actually possible in given monetary and timeline constraints.

MAKING YOUR OWN 3D CONTENT

The visual work on new 3D content typically starts by gathering references, making sketches and creating concept art to define the target look. For example, creating 3D characters and other assets usually starts with drawn 2d designs, iterated until final character appears. This 2d sketching step may also be skipped, by e.g. sculpting the character digitally and thus creating the sketch in 3D. For an experienced artist, such digital sculpting can be quite fast way to iterate between different designs until desired look is born—naturally the same goes for 2d sketching and concept art.

Final design is then made game-ready, typically by a process of retopology, where underlying sculpture is remade by continuously adding simpler polygons on the surface, or by straight low-polygon modelling. Both of these methods result in a game-ready mesh, which can then be UV-unwrapped for texturing or, if fitting, colored by ma-

Image 3: Roughly sculpted character and final low-poly character with clothing.

terial and vertex colors. Textures, which are 2d images mapped to the model and can be thought as pelts of it, can be created by hand-painting the unwrapped model, by assigning ready-made materials, by texturing procedurally, or by painting the high-poly model and transferring the result to game-ready model. While character artist will weigh the desired result to time constraints and decide the best way, for stylized, cartoony look the models are typically hand-painted while realistic looks might use scanned real-world material libraries combined with procedurally generated textures in addition to hand-painting.

For animation, this game model also needs to be rigged, that is, bones to control the movement of body parts must be set inside the characters, for example, an arm bone inside character's arm. Then the model needs to skinned, a process where points of the wireframe model are assigned to a suitable bone so that they move with it. Rigged and skinned model can then be manually animated by an animator or have motion capture data assigned to it—see section Motion later on.

All of these steps may have a specialized artist or tech artist in larger production, for example, digital sculptors separate from low-poly modellers, riggers separate from texture artists and so on. But on smaller projects, with less demanding final look, all parts may be filled by a single 3D generalist.

Pipelines are typically production-specific—not all styles of 3D models need unwrapping and texturing and not all styles need high definition digital sculpts. Choosing one that doesn't can cut production time and cost. If lots of similar assets are needed, it might make sense to partially automate asset creation, for example by morphing between different character traits (young, old, thin, plump, male, female etc.) or by making the models modular (like pieces of fitting equipment).

Game-ready models are also sold and some models or model tools have controls for changing the look of the character from thin to plump and from young to old and maybe even from realistic to stylized. These ready-made models and character generator tools may well be enough for certain projects and can improve production time depending on project complexity.

Image 4: Motion capture session during Sanan Seppä pilot project.

MOTION

Discussion about character motion in AR/VR applications typically comes to a choice between manual animation and motion capture. Animating the characters "by hand" requires a lot of time even for a professional animator. Therefore it is common to use motion capture (mocap) technology in productions where the characters move a lot and in different ways. In motion capture, real human actors do the movements while several cameras record the movements. While motion capture can be very realistic the data it produces needs manual clean-up to fix e.g. broken hand rotations, and in the end fixing the mocap data may take equal resources to manual animation. While there should be less and less capture errors as technology progresses, the motion is also a question of style—how realistic characters are and how realistically should they move. As such this is also an aesthetic choice and has no fixed answer, but a few pointers can be given.

Consider motion capture if

- The character motion should be realistic (e.g. human performing martial arts) and there are necessary resources for manual clean-up of mocap data if such need should arise.
- Mocap equipment is readily available, there's lot of animation needed and motion is simple enough to avoid motion errors or errors in motion data can be tolerated.

And, alternatively, consider manual animation if

- The motion is unrealistic, stylized or cannot be captured (e.g. a dragon).
- Animators are available, there is little animation needed and there's no mocap equipment readily available.

Basically, this boils down to using whatever you have at hand and what you're comfortable with, unless there is a clear need to use either one. Typically, in large production, both methods would be employed.

When animated characters are included in the production, it is a good idea to plan the work so that the 3D character models as well as the movements can be reused as much as possible. Automating some parts of the process would also help.

MOTION CAPTURE

In motion capture, real human actors do the movements while several cameras record the movements. Actors wear simple dark clothing, and point-like reflectors (markers) are attached to critical locations in actors' limbs and body, as seen in image 6. By tracking the reflectors in the recorded video by a special software the actual movements of the actors can be recorded in 3D space. The movements can then be applied to the virtual characters of the AR/VR application.

Motion capture can be done using consumer-oriented devices (e.g. Kinect[3]) but a better result and less work is needed if it is done in a proper mocap studio with professional equipment. While the principle is simple, the motion capture process is complex and there is typically a large amount of work needed to actually apply the movements to the virtual characters. This work requires experts, so it can be expensive.

Motion capture requires some training for the actors, too. They need to learn how to limit the movements within a limited space; movements may need to be restricted in order to avoid losing the tracking of markers, and because only a few persons can be recorded at a time, scenes with several persons must be done by combining several takes, and then the timing and locations of the actors become challenging. Some of these issues are easier to learn while some may require more practicing.

The number of actors that can be recorded simultaneously is limited. This is because if markers get obstructed, the movement tracking becomes unreliable. In simple scenes, it may be possible to record four persons at a time, but usually only two actors can be recorded simultaneously. Thus, scenes with more people must be done combining several recordings, and that causes challenges for timing and movements of the actors, so that the virtual characters don't move through each other and that the movements are in sync.

All recorded motions must be calibrated to the target characters. To do this, the actor does a "T-pose" (standing hands lifted pointing to the sides) whenever entering the scene in order to let the system identify each marker, and the pose is afterwards adjusted by the animator in order to accurately fit the motion to the target character.

Error handling with motion capture

Despite proper equipment and careful recording process, the recorded motion data still contains errors. Our experience is that, for instance, limbs may occasionally flip to unnatural positions when more than one marker gets obstructed, or sometimes when the actor is near the edge of the recording area, even when markers are visible.

Tracking errors must be corrected by manual editing. This is routine work done by the animator, but it can take a lot of time. In our Sanan seppä case, there were in total nearly 50 animated human characters, and the length of acted animation totalled to about X hours. Correcting errors from this material took several weeks of one person's time. The work included masking the erroneous movements with static poses of limbs.

If there are a lot of errors in mocap data, it is advisable to make a new capture rather than correct the errors manually. Manual work takes so much more time than recapture that even counting the cost of several persons and the studio, recapture will often become cheaper.

If the movements of small body parts like fingers are not essential, it is better not to capture them, as it would consume the processing power more than it is actually worth for. Facial details are another example of this dilemma: capturing those with high accuracy takes a lot of processing power, but facial expressions may be essential for the user experience. So the decision must be made case by case, comparing the costs and benefits.

Inverse Kinetics (IK) can be used when correcting the movements of limbs. In it, e.g. arms are animated by moving the extremities (hand), which in turn moves the connected body parts. Unity's Mecanim system contains such IK functionality.

It would be economical to make the motion recordings with as many characters as possible simultaneously, to avoid the work needed in syncing the characters afterwards. On the other hand, recording several characters causes more tracking errors. So, the best solution is a compromise, and depends on many factors, not least the equipment that is available.

To avoid unnecessary work in correcting erroneous mocap data, it might be a good idea to first build the scenes with uncorrected, broken data, and then fix just the needed parts and reimport them to the game engine.

During this project, Unity did not contain a timeline tool for easy timing control of scenes. Our solution was to use animation events triggered by one or more animations, and a specific content manager script that reacts to those events and drives other animations in turn. Unity will most probably get a timeline in the future, so this task will become easier to handle.

360 IMAGERY

What is a 360 video?

360 video, also known as omnidirectional video (ODV) is a video, where the captured view covers the entire 360 degree wide area surrounding the camera. The video is fully spherical so that the whole area is captured, also vertically. Spherical still images can also be made—a well-known example are the street view images in Google Maps[4].

360 videos can be viewed in different ways. The most immersive experience is when the video is viewed with a head-mounted display (HMD), a.k.a., virtual reality glasses. The user can freely look around in different directions by simply turning his/her head. 360 videos can also be beneficial with systems where the projections or displays cover large areas surrounding the user. With mobile devices, viewing is possible with a so called "magic lens" interface, i.e., the orientation of the hand-held device determines, which part of the video is displayed. The viewer can then naturally choose the viewing direction by moving the device around. 360 videos are often also viewed with regular desktop computers. For example, YouTube supports 360 video viewing so that the user chooses the viewing direction by dragging the video with mouse. In almost all practical use cases, the user is given a way to choose the viewing direction. Also, 360 videos can be either regular 2D videos or 3D (stereoscopic) videos. 3D videos can increase the immersion particularly in HMD viewing.

In most use cases the 360 video is displayed to the user with the aim of providing as natural view as possible. It is also possible to provide different distorted views. In some uses, other projections may be used. For example, small planet projection (the technical term is stereographic projection) is often used as it provides a very interesting and entertaining view. Other distortions and effects are also possible, which may, for example, enable making the video more interactive. To store 360 videos, the entire spherical video is usually projected into a regular, rectangular video using equirectangular projection. This enables the video to be stored using regular video file formats.

360 video versus 3D content

In immersive virtual reality, 360 video can be contrasted to 3D content created either by manually modeling (or utilizing existing

CAD models etc.) or by capturing objects and environments, for example, with photogrammetry or laser scanning.

Creating 3D content is in most cases a time-consuming process which requires high expertise. In contrast, capturing 360 videos is possible with very reasonable amount of training. The 360 video also captures a lot of details, and in cases where the content should match some real environment 360 videos can be particularly valuable. The weakness of 360 videos is that it limits the user's movement in the virtual world. The user can only move between separate videos, unlike with full 3D content, where free exploration can be enabled.

Creating 360 videos

A special camera or camera set is required to capture a 360 video. Many such systems are available and new ones are being released all the time. Image 5 presents a popular consumer-oriented 360 camera, *Ricoh Theta*[5]. Price range for 360-capable products starts from a few hundred euros and goes to tens of thousands of euros. There are several aspects that differ between the camera sets:

The camera sets include a minimum of two cameras with (at least) 180 degree wide angle lenses. (A single camera with a set of mirrors can also provide close to 360 video but such systems are not very common today.) Many solutions consist of more cameras. From the user point of view, the number of cameras is not particularly important. More cameras may provide fewer artefacts from the stitching of the separate pictures streams into a single video.

Stitching process, where separate videos are turned into one, varies between the systems. Many older systems require some manual work, like synchronizing the separate videos and optimizing stitching parameters. Most newer cameras, in particular the consumer grade solutions, take care of the stitching automatically. The benefit of manual stitching is that it enables some optimizations, e.g., small objects like part of a tripod holding the camera can be removed by carefully selecting which of the overlapping videos to use for each direction. Using high end algorithms can also result in a better picture quality than fast, automated solutions.

Stereoscopy support, i.e., whether the camera can capture 3D video is a distinct feature separating cameras into two groups.

Live streaming of the 360 video is possible with some of the solutions. However, in many cases, the resolutions of the live video is limited.

The resolution of the video is very important in 360 videos. Since one video file must contain information on all different directions, the video must have much higher resolution than a regular video. At the moment, 4K resolution is considered adequate for most uses but even that resolution is far from optimal. Some consumer grade solutions provide only Full HD video, which results in very low quality when viewed, e.g., with a HMD.

Robustness of the cameras also varies. If there is need, e.g., to attach the camera to the exterior of a moving vehicle, some setups may be too expensive and fragile.

Usability of the setups varies as well. In some systems, video capturing may require activation of each camera while others provide simple remote control. Control via a computer-based software is also used in some systems.

Camera synchronization is important especially with very fast moving objects and scenes. Best solutions are genlocked, i.e., every camera captures the frame at exactly the same time. This combined with global shutter cameras (as opposed to rolling shutter) with the same exposure time in each camera enables robust stitching of videos with fast moving objects with any exposure time setting.

Image 5. An example of a consumer-grade 360 camera: Ricoh Theta, which has two 180-degree cameras covering together the full sphere around the device.

When a 360 video is captured, there are various challenges and aspects to consider:

- Lighting can be challenging in 360 video shooting. Since all directions are captured, it is hard or impossible to hide any lights used for the capture. In uncontrolled conditions, e.g., outdoors, there are also often great differences in natural illumination in different directions. On one side of a scene there may be direct sunshine, while another direction may be in complete shadow. Depending on the tools, camera parameters may allow adjusting the lighting parameters but the decisions between over-exposing some areas or under-exposing others may be necessary.
- Especially when a 360 video is viewed with a HMD, camera movements can be very challenging. Camera movement, especially if it is not predictable, can cause cyber sickness in users. It is possible to stabilize the video, in particular camera rotations can be removed in post-processing. However, shooting videos with a moving camera should always be considered very carefully. Having at least a part of the view stable in the camera view can reduce the unpleasant effects. When the camera is attached to, e.g., a moving vehicle, the attachment should also be robust to minimize camera vibrations.
- Since the videos are stitched from two or more original videos captured from slightly different points of view (difference depending on camera setup), objects close to the camera are most problematic for stitching. Furthermore, especially in immersive viewing, objects close to camera may feel unnatural to viewers. Therefore, in most cases, the video should not contain objects near the camera.
- Positioning the camera is perhaps the most important decision when 360 videos are captured. In many cases, the camera is placed in a natural viewing position. The location is such where a person could be standing (or sitting) in real life. It is also possible to position the camera into an unnatural location, e.g., floating high in the air. This can be considered one of the benefits of 360 videos since it can put the viewer into a position they would not be able to go in real life. However, since HMD-based 360 video viewing is usually a very immersive experience, high camera positions may cause feelings of vertigo in some users. This may happen even when the camera is in quite natural location but near to a ledge, for example.

VISUAL PROCESSING

Quality of the visual output produced by the mixed reality application can have a significant impact on the user's experience. Often with mixed reality applications, the goal is to create an illusion in which virtual elements are looking as real as the physical objects in the environment observed by the viewer. Realism of mixed reality content improves the user's immersion and engagement as virtual content blends together with the reality seamlessly. However, photorealistic rendering of virtual objects is a difficult task, and even with the state of the art solutions available today, such seamless blending is difficult to achieve.

Compared with the real-time graphics used in the computer games, the difficulty with the mixed reality image quality comes from the need to embed the virtual elements with the view of the real world. In order to have identical visual quality, the mixed reality application needs to be able to simulate lighting conditions and materials of the real world when drawing the virtual objects. Also, when augmenting view of the real world captured by a camera, as is the case with augmented reality applications used with the mobile phones, virtual elements drawn by the application should be able to mimic the image quality the camera used for capturing the reality produces. This means that virtual elements drawn by the application should feature identical lens distortions, dynamic range, noise, etc. In practice, what is needed in the mixed reality image output is the same kind of visual processing and image composition that is used in visual effects production used in movies. Compared with the visual effects production methods used for film production, the challenge for the mixed reality comes from the fact that in the film productions, for producing a single frame, tens of hours of processing time and manual tweaking is often used, but for the mixed reality application same processing needs to be fully automatic and be performed in real-time, i.e. above 20 times per second.

In the *SelfieWall* pilot implemented for the Maritime Center Vellamo, requirements for the visual processing are slightly relaxed, as the operational environment is more controlled than for example with a mobile phone augmented reality application that can be used at any environment. In SelfieWall pilot, the goal is to blend image of the viewer as seamlessly as possible with historic photographs. In order to do so, SelfieWall application implements a real-time image post-processing pipeline used for creating similar look for the captured video image as is seen on the historic photograph. Post-processing involves several steps that include image color space transformations, adding of noise to simulate film grain and image space transformations to mimic artefacts caused by the camera lens such as blurring. In SelfieWall application, parameters used for video image post-processing can be tuned individually for each historic photograph in use, so in the same session, viewer captured on video can be blended with black and white photographs with various quality and color images with different color shifts.

In video see-through augmented reality applications virtual elements are composited together with the view captured by a camera. In comparison, in optical see-through augmented reality in which virtual objects are added directly on top of the viewer's natural sight it is more difficult to reach a seamless blending of virtual objects with the view to the real world.

Optical see-through augmented reality displays typically used by the emerging head mounted display products such as Microsoft Hololens, use some form of beam combiners to mix image output with a light emitting display element with the view the user has to the real world. Beam combiners can be for example half-silvered mirrors that cause two views to blend together. Problem with the optical see-through displays is that in the output of the image on top of the view of the real world, light can only be added not removed from the light that is already transporting from the real world to the retina of the viewer. This causes virtual elements appearing always semi-transparent, degree of transparency depending on the amount of light coming from the real world environment. In addition to this transparency shortcoming of the optical see-through setups, also displays available for

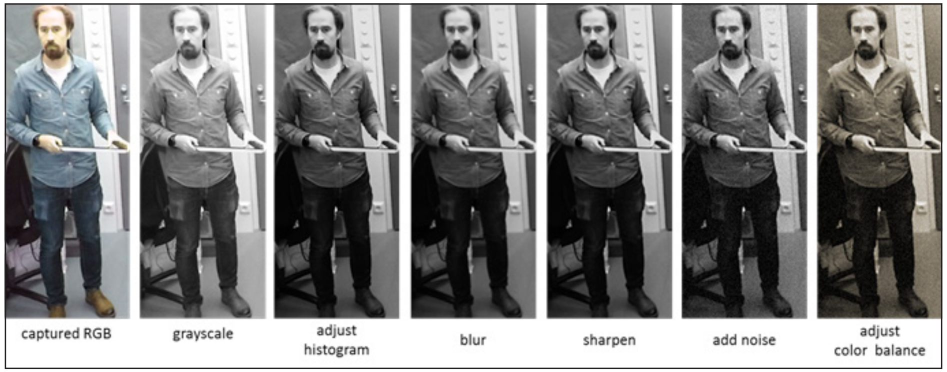

Image 6: Example of impact various steps of the SelfieWall image post-processing has on the image.

Image 7: Video image of a viewer processed and composited in real-time with the SelfieWall application.

these setups are not capable of producing dynamic range of luminosity or tone range nor resolution to match the sensitivity of the human visual system.

In the *Amos Anderson* pilot which uses a large scale optical see-through display, shortcomings of the display type have been addressed by accepting the inherent transparency of virtual elements by not trying to create appearance of virtual elements but rather using the display to enhance existing physical object by adding details to it with a virtual content. This approach requires delicate balance between the mixing of normal view to the physical object and amount of virtual content blended together with it. As the pilot was deployed at outdoor environment, constant change of prevailing lighting conditions made the problem of correct mixing of images quite difficult. At outdoor environments the range of light energy reflecting from physical objects has very big variation. With Amos Anderson pilot, this need to dynamically adjusting the amount of light output with the display element was addressed by developing a camera based solution for observing the amount of light reflecting from the physical object on top of which the virtual image was to be added and then controlling the brightness of the display accordingly.

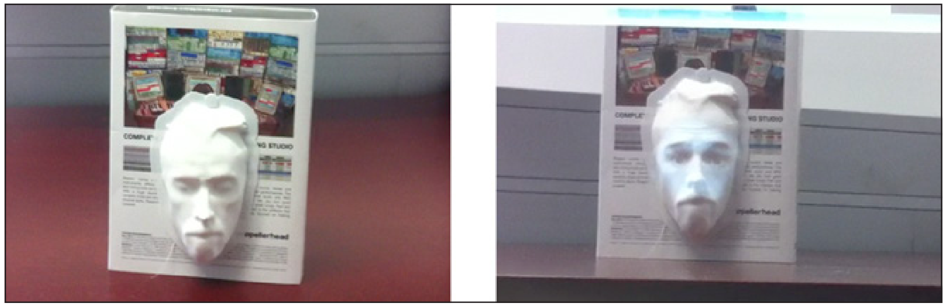

Image 8: Test object without overlaid virtual image on left and object with virtual image added on the right

SOUND DESIGN

Sound can be an essential part of a mixed reality experience. Especially when there is speech in the application, the user should be able to hear it clearly. Other natural sounds—made by animals, machines, moving objects and so on, are important for the experience. There are different options for how to reproduce the sounds, and it depends on many factors which is the most appropriate option.

Using the speaker in the mobile device is an obvious possibility, with the advantages that it is always available when the device itself is, and that more than one person can hear the sounds at the same time. In several pilot applications in the MIRACLE project the speaker-produced sound was used with good results. There are, however, also potential risks with this approach: sounds spreading freely can be a disturbance in places like museums, churches and so on, and having many copies of the app running simultaneously may cause a cacophony that disturbs people even in less delicate places.

Using headphones is one way to avoid disturbance, as it keeps the sounds in the user's ears. This is also a good solution in noisy environments. However, it means the headphones must be available, and people don't necessarily carry them all the time. Offering headphones for loan is a possible solution, but hygienic issues must be taken into account. Cheap headphones for sale may be a working solution in some cases.

Designing the sounds to be subtle may help in avoiding disturbances, even when using speaker-generated audio. This approach obviously affects the whole concept of the application and may exclude some otherwise good ideas for a mixed reality experience.

Making the audio experience as realistic as possible is a technical issue. The speakers of phones and tablets can produce sounds with more or less limited quality and volume, and the directions of the sounds can't be controlled much. Headsets of head-mounted displays, on the other hand, may be able to reproduce quite realistic sound environment with authentic sound volume, frequency response and directional characteristics.

Even with hand-held mobile devices it is possible to produce some basic sound effects. For example, when the virtual character turns away when speaking, the voice should become muffled, and when the character moves further, it should become quieter. To realize this, game engines have audio processing functions built-in and support third-party solutions.

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3.5 USER EXPERIENCE AND USABILITY

There are many definitions for the term user experience. These have different field-dependent emphases, for example marketing, human-technology interaction, or psychology. Approaching the issue in a simple manner within the field of human-technology interaction, as in [1], user experience can be thought as a user's subjective opinion about a certain aspect about the system in a certain context at that time. The primary users referred to here are the museum visitors, although for instance museum personnel maintaining an AR installation can be considered as users as well. Thus, user experience can be thought simply as a museum visitor's personal impression about an interactive installation at a museum.

In museum context, good user experience in general means that an installation is attractive, the users like to interact with it and they see it bringing some added value with regards to their museum visit. Depending on the type of museum and the purpose of the installation, the user experience aspects the installation is trying to evoke may also be much more specific. An obvious design goal for any cultural heritage-oriented application, or any museum installation for that matter, is that it should be easy to use, and it should be obvious from the start how to use it. Since many of these applications are mainly used on location, the users are often first-time users. If the application requires any significant learning, many users may simply stop using it before getting any good experiences from it.

The idea, story and content of an installation obviously influence a lot how the users experience it. See Section 3.3 Content creation for tips and guidelines on the content side.

Some practical guidelines for user experience and usability design are

- Use interaction style and widgets that most users are familiar with already. Traditional buttons and sliders on the touchscreen work well. The button functions should be made easy to understand.
- It can be useful to offer more than one way to achieve a task: for example, putting a virtual object somewhere on screen could be possible by dragging and dropping, or it could be done first tapping the object and then the place where it is to be put.
- For some users the concept of AR may be new and unfamiliar. For them there should be sufficient guidance about the ways of usage when starting up the app. It may be done with a video tutorial or some practice tasks before starting up the actual app.
- A tutorial is needed for ways of interaction that aren't likely to be familiar to everyone. For example, turning the device to horizontal orientation can switch on the map view, but the user might miss that if it is not explained.
- During the use of the app, tips about possible ways to proceed may be precious. If the user seems stuck, tell what could be done next or what to look for.
- Technical problems for instance with tracking can spoil the user experience badly. If this is at all likely to happen, the app should recognize the problem and give the user assistance about how to work around it. An alternative way to proceed could also be offered—for example, a 360-degree video can be played in place of the actual AR view when facing serious tracking problems.

Depending on the purpose of an installation and its planned deployment time, especially, it may be highly useful to evaluate its user experience on some level at least. The purpose, and thus the scale, of such an evaluation may vary greatly based on by whom and for what it is conducted. For example, if museum visitors' experiences on specific aspects, functionalities and solutions should be investigated for scientific purposes, the evaluation methods need thorough and professional planning. Similarly, an evaluation targeting to investigate the business potential of an application would require business-oriented professionalism when planning the evaluation methods and content. However, if the whole purpose of an application is to provide something new and nice to the museum audience, also the evaluation can be kept light. In such a case one could use, for example, a simple questionnaire to gather feedback from the users, or interview a few people. The inquired questions can basically be planned and decided using common sense without specific expertise: is the installation able to evoke the target experience(s), do people like the installation, why or why not, what could be improved, and so on. In a light-weight user experience evaluation the most important thing is to find out truly useful information, i.e., receive results which have a practical meaning for possible next steps. Possible issues, and also top features, can be sometimes revealed with surprisingly few test users. However, evaluating an installation at least somehow in real context with real users is important. This is because the people involved in the design and development process are easily too close to the matter, they may become blind towards the pros and especially cons. Tips for user evaluations can be found in the case study descriptions in Section 4.

ADDITIONAL MODALITIES

Vibration and other haptic feedback

Haptic feedback such as vibrations and force feedback can improve the user's experience. In particular, an installation which simulates some real world object or phenomenon can benefit from adding such elements. The vibrations and other haptic feedback are transmitted via some physical element of an installation, e.g., a seat, hand controls or even floor. Because of this, in most cases haptics are experienced by only the visitors who actively use an installation. People passing by can experience them only in some specific setups.

The road grader installation installed in automobile and road museum Mobilia (Kangasala, Finland) provides a pure example of vibration-based haptics adding natural and quite critical element into the experience. The installation aims to provide an experience of what it is like to drive an old road grader. It does not aim for full realism; visitors have only limited control over what happens and the physical setup consists only of simple, wooden frame with somewhat realistic steering wheel, seat and pedals. The haptic feedback included in the system is vibration feedback moving the seat. Since the old road grader is not a smooth ride, vibrations can be considered to be an important part of the experience. Installing the vibration element clearly improved users' experiences about the simulator (see Section 4.6 Case Mobilia I—the Road Grader Simulator for details).

The implementation of haptic feedback can be complex when advanced force feedback hardware solutions are used. However, simple vibration feedback can be included quite easily. Many haptic actuators of different sizes are controlled with audio signal. In the road grader installation, we utilized a single Buttkicker device[2]. It was installed in the frame under the seat. The device was attached to the plywood frame piece under the seat. Rubber feet included in the Buttkicker package were placed between the plywood and the rest of the frame, giving the seat and the plywood some freedom of movement.

To create the vibrations in the road grader installation, the same audio that is played back via a normal audio speaker is also sent to the Buttkicker. This audio was originally recorded from the cabin of the road grader. There was no need to create separate audio for the vibration purposes as the original recording had suitable, low frequency content.

Challenge with vibration feedback, especially with a strong one like in our installation, is two-fold. First, the vibration tends to create some audible sounds as well. These sounds can become loud if the vibrating elements start to resonate with the vibration. Second, the strong vibrations can cause enough physical movement to cause harm to the installation. Electrical connections can become loose due to the constant vibration and even screws may loosen, glue may break etc. The physical design of the installation can alleviate this problem by limiting the vibrations only to the components visitors are physically touching.

Physical switches

Tangible interfaces have gained popularity as enhancers of gaming and other interactive experiences. These tangible elements are also utilized in museum environments where visitors are encouraged to interact and explore different exhibits.

In the Vapriikki museum installation (Tampere, Finland)—the optical telegraph—physical switches are used to substitute the rope system used to control the shutters in the original version of the telegraph. The idea was that the switches would be a more robust solution while still providing the fun element to the interaction with the telegraph. Nine different toggle switches (ON/OFF states) are used to control the telegraph shutters. In addition, three buttons are used to control other aspects of the installation such as displaying information or changing the language settings. See Section 4.8 Case Vapriikki—the Optical Telegraph for details about the installation.

During the observation sessions, it was evident that the switches were effective in attracting children. Additionally, when being interviewed, some users expressed that the switches were a nice element in the installation. A couple of them said it to be the best part of the installation. One of the visitors said "The sounds of the switches" were their favorite part.

However, there is a drawback with the utilization of toggle switches in these kinds of installations. Because of their physical constraints, the switches affect the possibility to provide the same entry point of interaction to all users. In other words, new users trying to interact with the system will find the switches in whichever positions the previous user left them, which can cause confusion in problem-solving tasks such as the understanding of the coding principle in the telegraph installation.

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3.6 OBSERVATIONS OF NARRATIVE AR APPLICATION USED IN REAL LEARNING SITUATIONS

To many teachers that do not have earlier experience with AR, the concept of AR story can be hard to understand at first. Prejudice towards this kind of vague tablet application can even be negative. Testing similar application or seeing it in use, quickly clarifies teachers vision of how they could integrate this medium to their courses. Especially for cases where teacher doesn't have opportunity to test application with their own hands, it's recommended to provide basic information about AR as learning medium, contents of the this specific story and video demonstration of application in action. One good rule of thumb for marketing AR content to teaching purposes for teachers is to emphasize that this kind of applications are not designed to replace conventional teaching methods, but provide one new possibility that can work well with old ones.

Teachers that brought their classes to explore the Turku cathedral with Sanan seppä application as part of their high school courses or elementary school program, found that this kind of narrative AR could serve as either as introduction to subject matter or as deepening of already acquired knowledge. Reception and level of understanding of the story's meanings changes depending on how much context is familiar to user. One way to supply information that deepens understanding of story's meaning is to link application internally to formal information from different sources and have integrated UI for viewing this in real time between and during the scenes. Educational AR story should include deeper insights in its subject matter, but it also should be understandable without high beforehand knowledge. Succeeding in this makes application a versatile and non-restrictive building block for teachers planning their coursework in unique situations.

Class excursions to cultural sites usually have tight schedule and duration of story cannot be too long. 45 minutes is good estimation of maximum length for especially younger students to focus on one form of activity without breaks. If setting up devices and groups takes 10 minutes, this gives story a maximum length of approx. 30 minutes. Application has to provide working tutorial and helpful UI so users can start using it on their own and quickly begin to progress in story. Teachers and staff seldom have resources to instruct whole class one by one to use application. If a big group of students gets frustrated outside of the classroom, situation can quickly turn overwhelming to teacher who tries to control it.

AR applications are highly vulnerable to overcrowding and blocking of vision. This threat heightens when story progresses in linear order and forces big groups of users to same places at same time. Designing applications so that multiple users are able to use same device can ease the problem. Option to use application in small groups can also induce valuable group learning benefits. Other bold option to solve overcrowding is to design applications story in non-linear way, so that users can choose order of story progression. This design choice also increases level of user activity.

In general, AR technology includes an assumption of active user who changes his orientation in augmented space. Following AR story is by nature an activating experience. User has to actively navigate in environment and follow the virtual character in scenes. This user activity aspect of AR medium also contains a big risk. If finding the scenes and following the events feels tedious, frustration quickly destroys learning motivation. Other practical consideration related to active nature of AR is user ergonomics with hand supported tablet devices. If scenes are too lengthy or require high viewing angles, holding the device up can feel exhausting.

Users following AR story might

have troubles to realize that they are free to orient themselves with high degree of freedom. Potential of active participation in scenes is often not fully realized. Primary reason behind this is technical challenges that restrict the freedom of tracking in many situations. If tracking drops, user is programmed with negative outcome to keep static pose. With unknown technology, users are easily mimicking others' successful actions and static pose that works is often replicated between users.

Difficulties to use freedom of orientation can also be related to design choices of storytelling. User can be guided to movement with visual and audio clues and inducements. Users' attention can also be encouraged with integrated elements in application like real time quizzes or treasure hunts mechanics. The more user is encouraged to pick details of his liking more he/she realizes the different ways of following the story.

Why narrative AR app can effectively supplement elementary and high school education

- Combining narrative presentation with analytical information is invigorating and effective, finding right balance between captivating drama and factual content is important.
- Answers to current curriculum plans requirements for learning environments that experiment with new ICT possibilities and utilize out of the classroom learning possibilities.
- Provides one genuinely new medium for informative storytelling that fits well with ideas of phenomena based, multidisciplinary and active learning. AR storytelling has lot of potential to activate and motivate user, that can be realized with creative use of medium's special nature.

General challenges with narrative AR app in elementary and high school education

- Engaging presence with historical environment demands smooth tracking and quality visual assets.
- Story with pedagogical value requires comprehensive and multidisciplinary presentation of setting and attention to details. If story wishes to utilize AR's potential, thoughtful design is required.
- Teacher must plan carefully how to integrate AR story experience to course work so that different modes of learning support each other effectively. Application should support it's versatile use in different curriculum needs.

Practical considerations about narrative AR application in education

- Designing balanced duration to story and individual scenes is important.
- Overcrowding problems must be acknowledged in design process
- Getting smooth start with application is emphasized with big classes. Good tutorial and helpful UI is important.
- Story should be understandable and meaningful to users with different knowledge levels. Supporting formal information can be provided inside the application.
- Application should be designed to be versatile tool for teacher and support unique teaching needs and plans.
- Informative info package can help to market application to teachers and break negative prejudices.
- Positive activity and freedom can quickly turn tedious work with bad design and technical problems.
- Users can be encouraged to utilize freedom of orientation with visual and audio clues and integrated modules like quizzes and treasure hunts.

4. CASES

This section describes pilot applications designed during the Futuristic History project (2013–14) and MIRACLE project (2015–17). The intention is to give insight into practical questions about application develowpment, potential problems that may be encountered, and results that can be achieved.

Pilots by University of Turku

- *Luostarinmäki Adventure*
- *Sanan seppä / Wordsmith*
- *Museum Explorer*
- *Häme Castle*
- *House Casagrande*

Pilots by University of Tampere

- *Road Grader Simulator*
- *360° Rally Simulator*
- *Optical Telegraph*

Pilots by VTT

- *Miracle Wall*
- *Amos Anderson*
- *Radio Waves*

Pilots by University of Helsinki

- *How to Fly*
- *Molecule Movements*

4.1 LUOSTARINMÄKI ADVENTURE

Luostarinmäki Adventure is a tablet application that takes a visitor of the Luostarinmäki Handicrafts Museum in the middle of the 1850's daily life in Turku. The user of the app sees digitally created characters on screen, in the actual environment, and can have a dialog with them by choosing phrases on the device. The adventure was originally built in the Futuristic History project in co-operation with the museum personnel and the project researchers, and developed further in the MIRACLE project.

Image 1. Looking through the tablet application, museum visitor meets digitally created characters in the streets of the Luostarinmäki museum.

THE LUOSTARINMÄKI HANDICRAFTS MUSEUM

In 1827 the city of Turku in southwestern Finland was mostly destroyed in the most devastating fire in the Nordic countries through history. The only larger part to remain intact was the Luostarinmäki area on the outskirts of the city. In a new city plan drawn after the fire, the Luostarinmäki area was rearranged and thus the old houses were ordered to be demolished[1]. However, rebuilding of the city took time and the demolition of the old houses in Luostarinmäki was never carried out, and the houses preserved their 18th century features. In the first half of the 20th century the cultural-historical value of the area was recognized and the buildings were conserved. The Luostarinmäki Handicrafts museum was opened in 1940 to represent traditional handicrafts and life of the people of limited means in 18th and 19th century city[2].

GAME-BASED MUSEUM EDUCATION

According the definition set out by The International Council of Museums (ICOM), the duties of a museum include promoting education, providing enjoyment and communicating information about humanity and its environment (ICOM Statutes). At its best, a museum is also an experiential and creative place where learners can investigate and experiment firsthand. Seen from this context, it is interesting to consider how an augmented reality game serves the learning environment of the Luostarinmäki Handicrafts Museum. What kinds of potential influences could gamification and augmented reality have on the museum experience and learning at the site?

A place like the Luostarinmäki Museum can be an unfamiliar and challenging environment to present-day people, many of whom have never lived without running water, electricity and other necessities of modern housing. Few visitors know how or for what purpose the tools they see were once used. Augmented reality and gamification can help visitors to process the historical details and connect them with things learned earlier. Gamification, the use of video game elements in non-gaming systems to improve user experience and user engage-

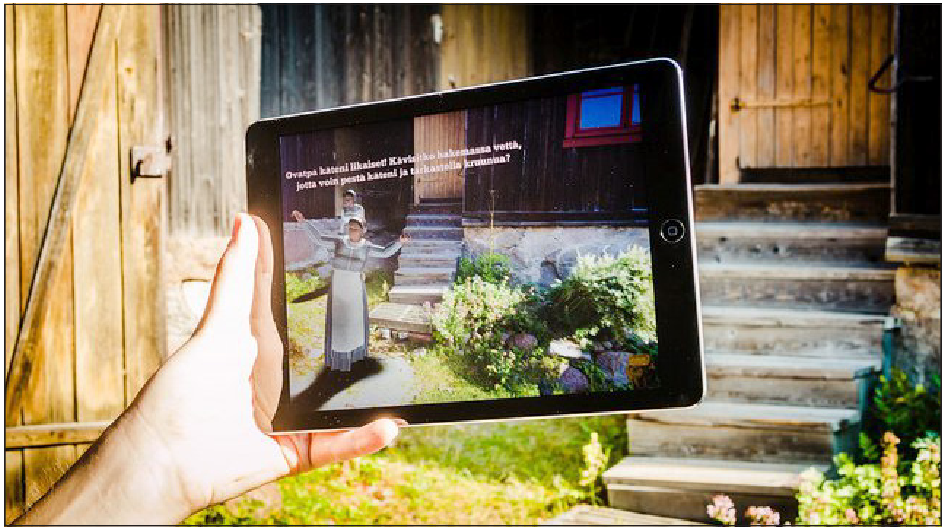

Image 2. Attempting to deliver the wedding crown.

ment[3]. An engaging experience has long been recognized as of great significance[4]. Games can help learners find the motivation needed for all learning. A successful game engages the player, becomes personalised with experience, motivates, and creates strong memory traces[5].

Although the Luostarinmäki game is fictional and tied to a storyline, learners are provided with a lot of information about history, objects and life in the olden days. The game motivates learners to investigate and look for more information about the site. The combination of physical and digital environment gives learners new opportunities to see, hear, feel and experience things that would not be possible without augmented reality.

THE STORY

The Luostarinmäki Adventure represents daily life in 19th century city through an entertaining experience. The aim was to create a mobile adventure game for young adults, which would be entertaining enough to keep the player engaged in playing. The museum staff was asked to list things in the 1850s life they considered worth representing but which have been impossible to bring forward until now. Already the first version of the manuscript was based on these wishes and written by history and museology students in co-operation with the museum staff and history researchers at the University of Turku. The aim was to integrate interesting facts within the events and the plot, instead of presenting them traditionally in textual form.

The events in the game take place on one Saturday in the summer of 1855. The player takes the role of Frans Hakala, a 23-year-old man from the countryside, coming to Luostarinmäki to take part in the wedding of his cousin. Because the character comes from countryside, he, just like the player, is unfamiliar with many things in a 19th century city, and people he meets must explain them to him. The first task is to deliver the wedding crown of the family to the bride's mother. It is soon revealed that the wedding ring has been stolen from the groom. The game then takes a form of a detective story in which the player has to follow clues and find the thief and the ring to save the day.

During the first task the player will among other things learn that there were no street addresses in the 19th century city, that nearly every house had some domestic animals, that master and mistress had the right to discipline their servants, that water had to be brought from a distance and that there were saunas inside some town houses.

The Luostarinmäki adventure turns a tablet computer into a window to history. Yet, there lies a risk in being too realistic. Representations of the past are always only interpretations made by the museum staff, the historians, the artists and the engineers. The more complete the given interpretation, the less the users need to make their own[6]. At worst this may lead to an oversimplified and one-dimensional picture of the past. Visitors have to be encouraged to be critical, and it should be made clear that the representation is not the absolute truth about the history. In the case of the Luostarinmäki adventure this means explaining the player the all but self-evident relationship between fact and fiction in the story.

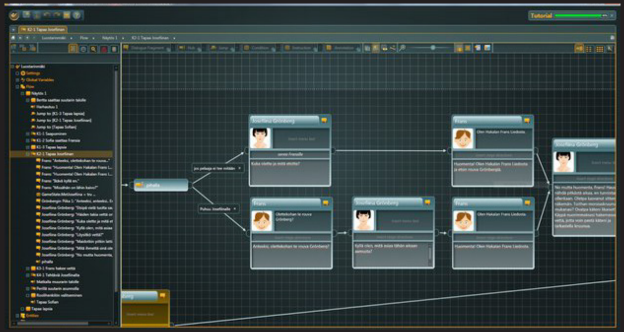

Image 3. articy:draft tool was used to create the script for the story, including discussions and user choices.

Image 4. In Unity Multipurpose Avatar numerous adjustments were available to create different appearances for the virtual characters.

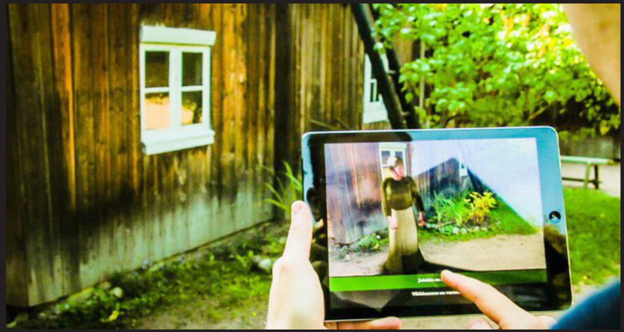

Image 5. Dialogue interface. While discussing with game characters, the user chooses one of the alternative lines as his/her reply.

Image 6. Map view. Holding the tablet horizontally, user sees the map of the area with indications of the current location and the place that should be found next. The small photo gives a further hint of the place to look for.

Image 7. The inventory can be opened by tapping the backpack icon in the bottom right corner of the screen. The items carried are now seen on the bottom area of the screen

THE TOOLS AND PROCESSES

The goal with the Luostarinmäki application was to allow the user to experience the augmented world while moving freely around the museum. There are several AR solutions readily available, but many do not fulfill our initial requirements. Many solutions are based on highly visible graphic prints (markers, triggers or targets) placed in the environment to aid the tracking process. Such markers would not be acceptable in the museum environment, so a solution without added visual aids was needed. The markerless point cloud tracking of the ALVAR library[7] by VTT Technical Research Centre of Finland was used in the Luostarinmäki application. From a large amount of photographs of the environment a virtual representation of the area is calculated algorithmically. This virtual version, the so-called point cloud, is then used as the tracking target, eliminating the need for any additional markers in the environment.

DEVELOPMENT TOOLS

An application targeted to wide audiences should work in a variety of mobile devices, thus the concept of multi-platform development was adopted from the start. The Unity game engine[8] was chosen as the main software development tool. Unity provides much of the initial architecture needed in complex 3D games and supports common desktop and mobile platforms. The initial script from student writers was refined with a scripting tool called articy:draft[9]. With it the storylines can be visualized and the non-technical script writing process integrated into the actual implementation of the application.

Creating realistic human characters is very time-consuming. A single lifelike 3D model of a person, with realistic clothing, fluid motions, and natural voice can require weeks of work by several skilled professionals. Limited-budget work requires more efficient methods. In this case we used the Unity plugin Unity Multipurpose Avatar (UMA, currently in version 2)[10] that provided us with all the necessary basic functionality to reuse and mix both character and cloth base models. For animating the characters we used data from the CMU Motion Capture Database[11]. No database of clothes of the era could be found, so they were modelled within the project using Blender software.

USER INTERFACE

The goal of the project was to develop a gamified adventure, inheriting elements from the adventure games genre but still “not obviously being a game”. Many of the users of such an application are first time users, so it must be easy to adopt, yet efficient, error-proof and satisfying to use. The idea in visual design was to skip traditional game elements such as crosshairs, health bars and minimaps in favor of a clutter-free interface of the main adventure view. In the dialogue interface the virtual characters’ lines of speech are drawn visible over their heads, and the user can reply by tapping on one of the alternative sentences.

Supporting elements like task hints and a map were placed into a separate view that appears when the tablet is leveled down into horizontal orientation.

When the user gets involved in a task, there is typically some interaction with virtual objects. Those things are carried in a virtual “backpack”, and they can be given to the virtual characters.

USER TESTING

After the initial software development phase, some user tests were carried out in parallel with User Interface and application development. Someone from the development team was following the test user and helping with technical or usage problems. Opinions of the test users were collected with a simple questionnaire about the content, usability and user experience of the application. A majority of the users found the experience of augmented reality pleasant or rather pleasant and thought that the application provided added value to the museum tour. However, since the game and the questionnaire were both modified through the testing period, and since most test persons were in some way connected to either the museum or the research unit, the results can only be considered indicative. The testing primarily served for development of the user interface and technical solutions. A clear source of frustration for the users was losing the tracking; they both blamed the software and questioned their own computer skills—usually simultaneously. One important issue noticed during the user testing was some kind of loss of the traditional museum experience while using the adventure. Some users felt they were too immersed in the application and forgot to pay attention to the surrounding museum. According to preliminary assumptions, the tablet was thought quite heavy and thus the users' hands got tired after some time. Moving from one place to another was a welcome relief to some of the users. One practical issue was that the scenes occurring in the courtyards could interfere with other visitors. Therefore, scenes should be arranged at the sides and corners of the courtyards.

Another test period was carried out after developing an improved version of the adventure. This phase was done as part of the MIRACLE project, and the study was conducted June 1st to June 18th 2015. The data, including basic user data as well as usability data and personal experiences, was gathered in a structured questionnaire built in the application from a total of 129 persons that were randomly recruited museum visitors. An analysis of these tests is published; see[12].

RESULTS AND CONCLUSIONS

The AR-experience in the Luostarinmäki was found to be very pleasing and, combined with the perceived value added, it clearly indicates that there is a demand in enhancing the museum experience with augmented reality content. The testees were quite pleased with the idea of using a tablet for an augmented reality adventure in a museum-style heritage site even though the site itself was not as easy terrain and thus not as accessible for everyone as one could hope for, and there were challenges in some technical functionalities. The storyline was found good and the length of the adventure (45 min) was found proper. The amount of historical elements to the story were found a tad wanting but overall for a product that is among the first of its kind the reception was very favorable.

Questions about app pricing and delivery—app downloaded to user's own device vs. device offered for loan in the site— were also presented to users. The opinions varied and the data does not provide definite answers to commercialization, and it must be kept in mind that the app tested was a prototype.

An important issue found during the project is the notion that users tend to forget the museum around them while concentrating in the game. Our view is that the tablet should not be the be-all-and-end-all solution, but instead more about enhancing the experience. It should only be used occasionally, and otherwise the users should be let to rest their hands, move safely, and enjoy the new, spiced-up museum experience. We learned that the application should guide the user better in the game. Technical issues have affected user experience significantly, which is not surprising considering the application was still on prototype level, not a polished commercial product.

Using AR technology, information can be provided without interfering with the physical reality in museums like Luostarinmäki, where outside areas and interiors have been kept as authentic as possible. It also allows for a much more diverse provision of multimedia learning content than physical solutions could offer. AR technology can open up things that are difficult to understand or topics that are abstract, making them more concrete and easy to understand than traditional educational methods.

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4.2 SANAN SEPPÄ / WORDSMITH

The Sanan seppä (Wordsmith) augmented reality application is located in the Turku Cathedral and tells about the changes in the local life caused by the Protestant Reformation in the 16th century. The application is connected with the marking of the 500th anniversary of the reformation in 2017, and it is created during the MIRACLE project, in cooperation with the Turku and Kaarina Parish Union and Evangelical Lutheran Church of Finland.

An objective for creating the app was to study presenting intangible cultural heritage[1] via augmented reality technology, in easily comprehensible form and in authentic locations.

The Sanan seppä Mixed Reality application will take the visitors in the Cathedral to the year 1514, that is, to the situation before the reformation. It then represents the changes during the following decades from a viewpoint of a fictional family. The story, written by author Tytti Issakainen, is told by using objects and historical characters digitally added in the church and made visible on tablet computers. The goal for this app has been to create an experience that is both educating and entertaining. The story is told through eight short scenes in which Hemminki, a son of a blacksmith, becomes an assistant of Mikael Agricola and the progenitor of a priest family. Agricola was one of the most important characters of the Finnish reformation, renowned for his printed works that started the spread of literacy among Finnish common people.

The application runs on a tablet computer, and follows many of the design principles used in the earlier Luostarinmäki Adventure app. The user sees the scenes on the tablet screen through the device camera view where the virtual characters are added. Besides the actual scenes, the app provides information about the characters and events in the story as well as references to background information in the internet. However, in this case there is no interaction between the user and the virtual characters—the user is just an observer of the scenes in the app.

THE STORY

The Sanan seppä will take the visitors in the Cathedral to the year 1514, that is, to the situation before the reformation, and then it will represent them the changes during the next 150 years from a viewpoint of a fictional family. The story written by author Tytti Issakainen is told by using objects and historical characters digitally added in the church and made visible by tablet computers. The characters include both some prominent figures of the Finnish reformation and common people. The goal has been to create an experience that is both educating and entertaining. The users of the application follow through eight

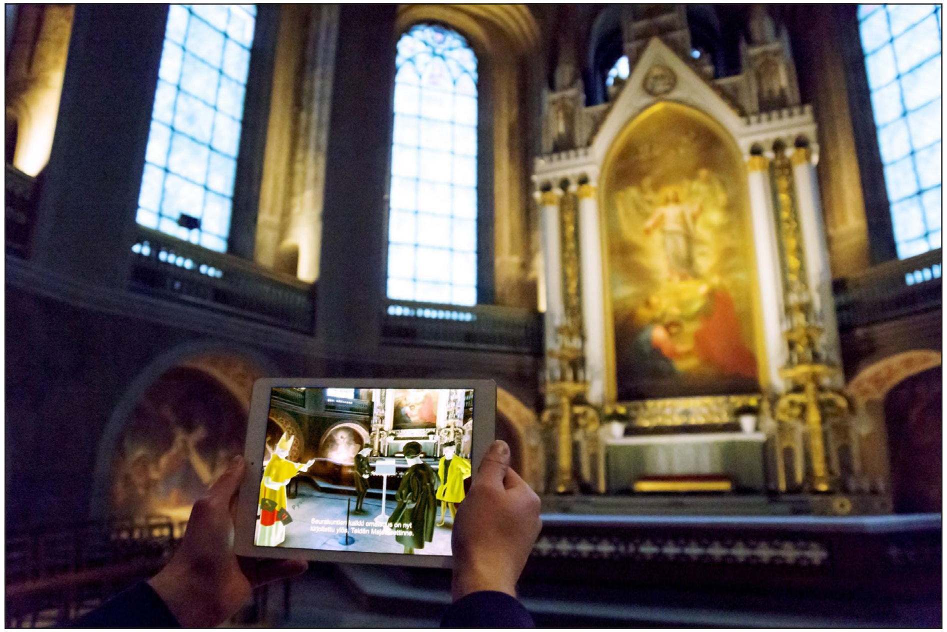

Image 1. The Sanan seppä app runs on a tablet computer and displays fictional scenes from 16th century, when Lutheran reformation changed the lives of Finnish citizens.

short scenes the story of Hemminki, a son of a fictional blacksmith as he becomes the assistant of Mikael Agricola, one of the most important characters of the Finnish reformation, and progenitor of a renowned priest family.

DEVELOPMENT OF THE APP

The augmented reality solution for the app is based on markerless tracking technology. In a historical environment such as the Turku Cathedral it is essential to avoid adding any visible markers to aid the augmented reality tracking. In this app, the coarse positioning solution is based on Bluetooth beacons that are discreetly placed in non-museal objects, like lamps and speakers. Exact positioning and tracking is based on visual tracking of point clouds made of permanent structures in the cathedral. Unity game engine[2] acts as the software platform, and ALVAR library by VTT[3] is used for the visual tracking. Mobile device first calculates the approximate location of the user based on the beacon signals, and the application will then choose the scene that occurs at or near that location, and search for the corresponding point clouds in order to do the exact positioning. The app displays a guiding image of the location of the scene to help the user finding it.

For handling the virtual elements in the app, a software framework designed within the MIRACLE project, described in 4.3, is used. It includes database connections, allowing digital content—for example 3D models, images or text—stored in various data sources to be retrieved and included in mobile applications. Virtual world positions of the objects can be managed via web interface, which also allows a selection of a tracking technology to be used with particular virtual objects. The framework introduces well-defined interfaces using eg. ARML (Augmented Reality Markup Language) standard. A goal in the MIRACLE project is to design this framework as a tool for museum personnel for updating and adding content in the AR applications used in museums—also for persons not highly skilled in information technology and software development.

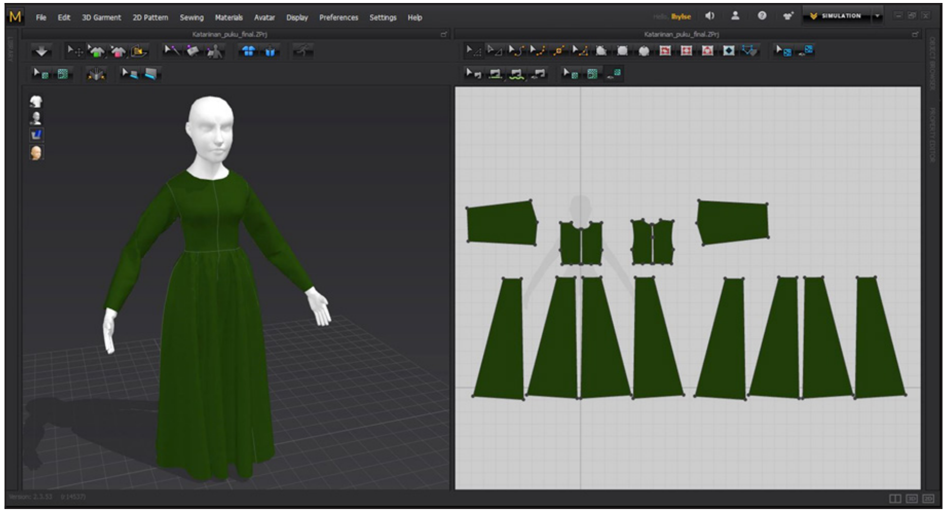

Image 2. Marvelous Designer is an application for designing clothing for 3D games.

Image 3. Some characters with clothing.

The app also uses a reference apparatus, which allows the user to find more information about the characters and events in the story. Part of the information is included within the app, while more extended descriptions can be found via links to web pages, where the content is structured according to the app.

The virtual characters in the app are modelled by a graphical designer using several tools, including Blender software[4], Substance designer[5] and Substance painter[6]. The number of characters appearing in the scenes is quite high, but the amount of work to make those was reduced by making parametric variations from a small number of basic 3D characters.

Clothing for the virtual characters was made by a historian, using a clothing design software called Marvelous Designer[7]. It took a few days to get onto productive level with the software, which we consider to be a good result. The intention was to avoid iterative phases and extra work needed in case a graphical designer had done the clothing based on descriptions and feedback by the historian. In this case the expert on clothing was able to do the digital design herself.

Animation of the human characters was done using motion capture technology. Amateur actors rehearsed all the scenes, and they were then recorded with motion capture equipment in a special studio during one day. The collected motion capture data required a significant amount of manual work combining and correcting the captured movements before taking them into use. More about motion capture can be found in section 3.4.

The app can be downloaded free of charge to user's own Android or iOS tablet at Google Play or AppStore, or a tablet can be borrowed from the cathedral entrance.

LESSONS LEARNED

Making an application as extensive as Sanan seppä requires lot of work by professionals with different kind of skills, but the result can be worth the effort. However, if the historical content and educational goals don't necessarily require such a complicated mode of representation, it is reasonable to consider another means of representation.

Narrative applications with fictional elements can be informative and an excellent way to convey information about complex historical phenomena. However, it is crucial to inform the users of the application about the extent and nature of uncertainties or fictional elements within the application. This is also recommended in the "London Charter for the computer-based visualisation of cultural heritage"[8].

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4.3 MUSEUM EXPLORER

Museum Explorer is a set of software components that together form a platform for creating and displaying augmented reality content in museum environments, and also outside actual museums. The main elements of the platform are a web content management system for creation and maintenance of digital data targeted to augmented reality applications for cultural heritage sector, and a software development kit for building augmented reality applications in the Unity environment.

CONTENT MANAGEMENT SYSTEM

The MuseumExplorer Content Management System (CMS) is a *MeteorJS*[1] based system that provides technical developers, content experts and eventually even casual users interfaces to access and modify the recorded data. Dedicated user interfaces are targeted for each target group. A main objective for the system is to provide a simple interface for museum personnel—people that are experts in the subject matter of the museum but have no technology expertise—to modify and maintain the digital content and create experiences for the museum's visitors.

The system models required data in a similar fashion to the *ARML 2.0 standard*[2].

The main object categories are

- **Applications:** To allow multiple productions to run on the same platform/installation, all other content and user management is filtered based on the parent application.
- **Assets:** Pieces of visual content to be displayed to the user: Images, 3D models or targets. Targets provide the AR trackers the registration data such as target images, point clouds or 3D spatial maps.
- **Features:** Describe how the end users access and consume the AR content. Combine assets (especially ties the targets with other assets) into larger contexts for example as a 3D scene.
- **Viewpoints:** Define geolocation or bluetooth beacon trigger based areas where different sets of content are available.
- **Overlays:** Additional maps to be used in the editor and the target applications for providing custom experience in addition to possible 3rd party map provides (such as Google, Bing, Apple).
- **Annotations:** Pieces of textual information attached to features.

The system provides a 3D editor for use in web browsers to create and edit the Features. The editor can be used to place Assets into a 3D space and combine them with Targets and Annotations. A simplified interface is provided for more casual and non-technical users, such as the museum staff, allowing limited functionality, but having enough functions for most common usage scenarios. The idea is that with minimal training museum staff can extend and update information in databases and create new "applications", or tours and exhibitions that are based on the existing information and objects. Once the data is fed in or a new application is defined, it is available via a Museum Navigator app. A prototype CMS interface for museum personnel is shown in image 1.

PRESENTATION PLATFORM

The ME Unity SDK is used to make end user applications presenting the virtual content and data created via the CMP part of ME. The SDK is built for and tested on the iOS & Android platforms, but most functionality should be compatible with platforms supported by Unity and the connected 3rd party tracker. The components and their functionality follows the scheme and roles defined in the MuseumExplorer CMS. The SDK can connect to the device sensors (camera, gyroscopes etc.) and it has tools for creating interactive experiences, such as following a storyline and providing synchronized animation, audio and subtitles. A plugin for the ALVAR tracking library is provided, too.

Using this platform it is possible to implement e.g. a Museum Navigator app, intended for end users, for displaying the virtual content from the CMS.

PILOTS BASED ON MUSEUMEXPLORER

MuseumExplorer elements were used in some pilot implementations in the MIRACLE project. Especially two cases were made to test-drive the platform: the DIY Exhibition was piloted in the Finland 100 citizen space in Turku, and the museum personnel interface was tried in the National Museum in Helsinki.

DIY EXHIBITION

The Museum Centre of Turku was hosting a “citizen space” in a shopping centre in Turku in the winter and spring of 2017. The Make Your Own Exhibition app was given to visitors there for testing. The app ran on a tablet computer, and the user could set a number of historical objects virtually into the space as an exhibition. The objects were selected from the archives of the Museum Centre Testers were more or less randomly selected passers-by, although a press release about testing was distributed and there was a poster about the app in the space and some other locations in Turku. Feedback was collected with a questionnaire that the users could fill in after trying the app.

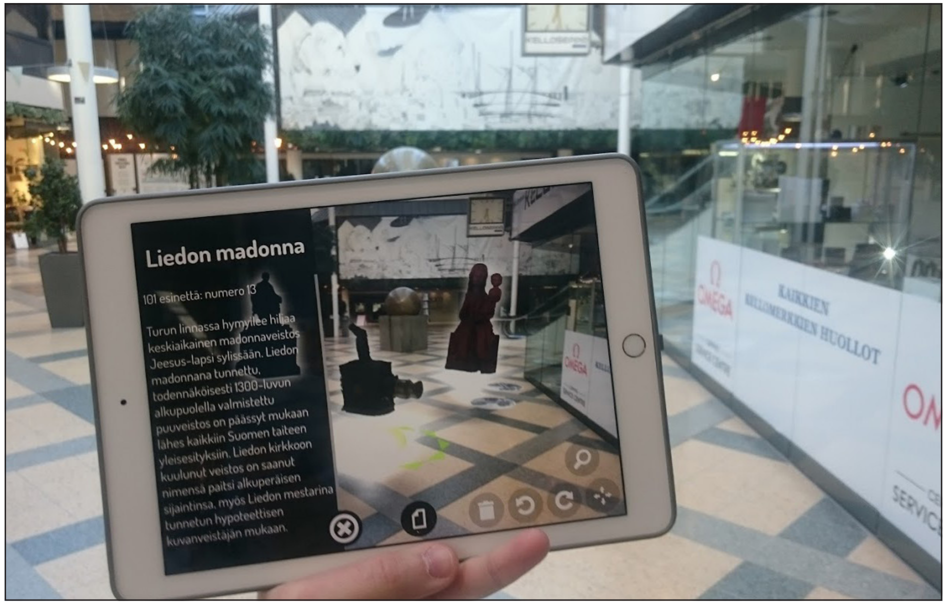

Image 2. Virtual exhibition experience.

MUSEUM PERSONNEL INTERFACE

The web interface of the Content Management System was demonstrated to volunteers of the National Museum’s personnel in Helsinki- in a half-day session. There were a handful of sample museum objects (on display in the actual exhibition) acting as test material that could be used to create “applications”. The web interface allowed selecting objects, positioning them into a virtual space, and adding information such as textual descriptions into the database. The participants could edit the augmented reality data via the interface, and the results could be observed via the navigator app at the actual objects. This was a very preliminary trial of the concept, but the feedback indicated that there is interest towards augmented reality applications among museum personnel. The trial raised discussion about topics like how much employee resources would such systems require and what kind of tasks can be expected to be taken care by non-technical museum staff. No definite answers to these questions exist at this point.

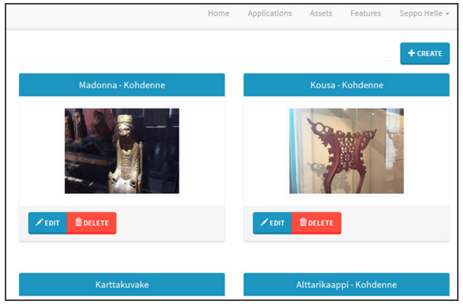

Image 1. Web interface can be used to design museum tours and virtual exhibitions.

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4.4 HÄME CASTLE

Transformations of the Knights' Hall is an augmented reality application located in the Häme Castle, Hämeenlinna. It is designed as a museum guide experience describing the changes in one of the castle's halls during past centuries. Oldest parts of the castle date from the late 13th century but the castle has experienced many kinds of building phases and uses through centuries[1].

The Knights' Hall got its present appearance, a single large open space, after the demolition of the prison-period constructions, which was done during the 1950s. When the castle served as a prison, there were several floors and prison cells in the space. In the 16th century the hall had a vault that made it lower than the current space.

The application visualizes the two periods with skeleton-like drawings displayed in their actual positions on top of the real-time image. The user can freely move in the hall and look at all directions "through" the tablet, to see the augmentations. Two time periods can be chosen: the middle ages (1500) when the hall was the reception hall of the castle bailiff, and the prison period (19th and early 20th century). The application contains also additional information about the hall's history that the user can browse.

The applications was in test use during February 2017 in the castle. Visitors to the Knigths' Hall were given a tablet computer with the app, and they could use it while in the hall. A questionnaire was offered after that. Feedback gathered from the questionnaire, and comments from the castle guides, indicate that many (roughly half of the) visitors see augmented reality as a potential approach for enriching the visitor experience in museums and historical sites. Most would like to see more realistic representations of the historical constructions than the simple drawings. Holding the tablet was tiring according to most users. Some felt that it would not feel convenient to carry and use a device while visiting a museum. Technical problems with the tracking did weaken the experience of many users.

A display freezing feature would lessen the problem of fatigue while holding the tablet up. With it the user can at any time set the view on hold, lower the tablet to a more comfortable position and continue observing and browsing the content. Presenting more reconstructions, and making them more detailed than in this pilot, would also very likely improve the experience for the users.

Image 1. The current form of the Knights' Hall. Remains of the vaults are visible in the walls.

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Image 2. Vaults and walls of the hall displayed as augmentations.

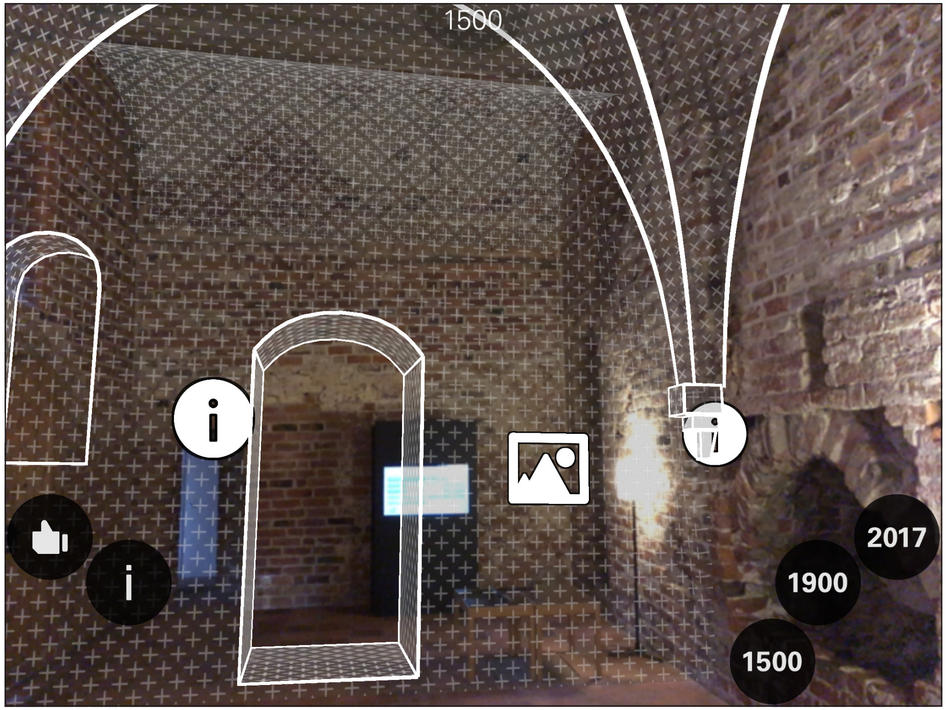
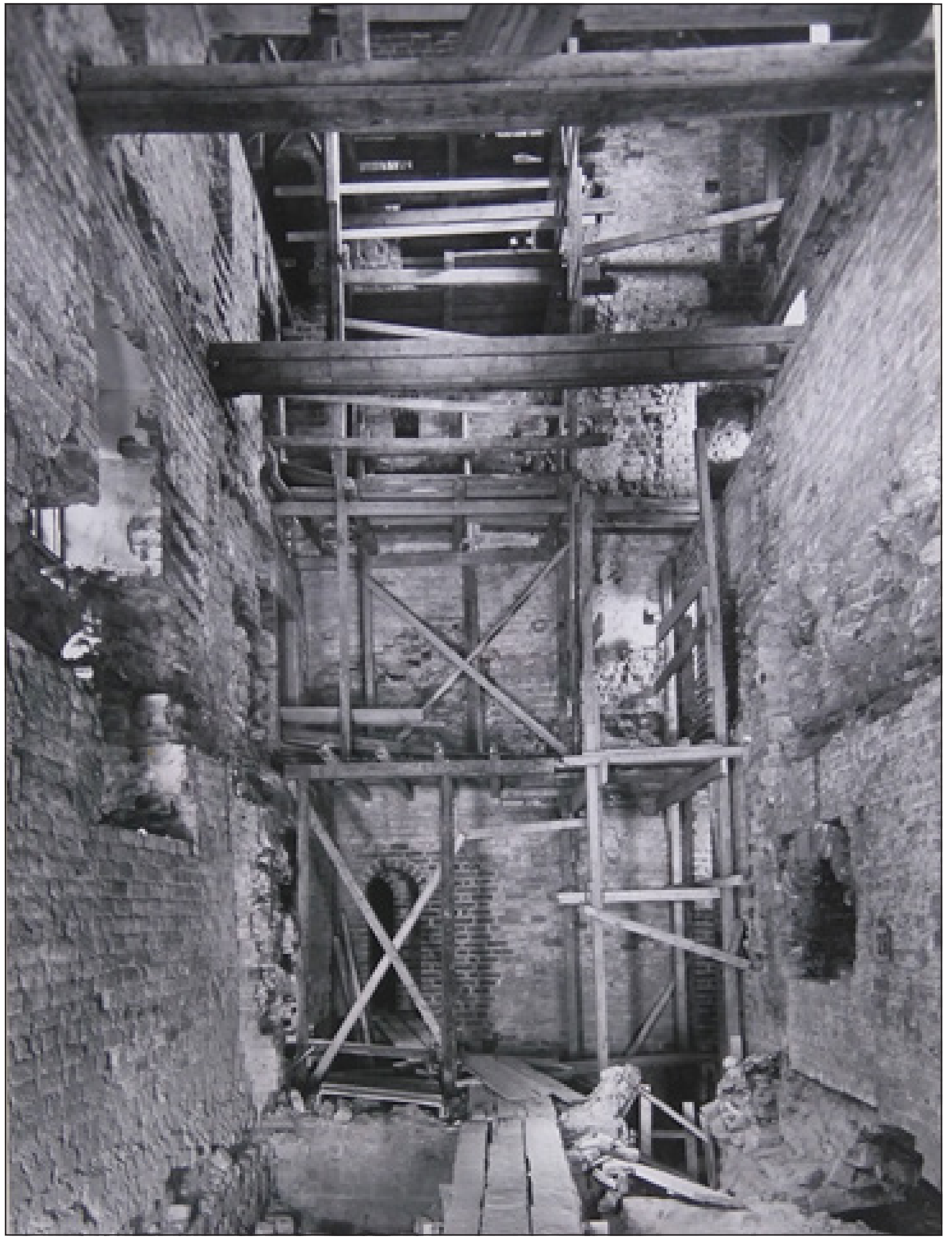


Image 3. Photo taken during the restoration of the castle, prison-time constructions being removed.



4.5 HOUSE CASAGRANDE

The House Casagrande pilot is a tablet application that visualizes the buildings situated earlier in the residential quarter now occupied by the House Casagrande in Turku. The buildings can be viewed in augmented reality from the Linnankatu street in front of the House Casagrande. Several periods between years 1588 and 1790 can be chosen in the application.

3D models of the historical buildings are based on archaeological and textual sources. The models were created by an architect with guidance from archaeologists and historians.

The architectural models could not be used directly in the app. This could be expected, as architectural models in general contain information about the internal structure of the building and other details that can't be seen in a visualization such as this application. Visualization models only need to contain data that can be seen, and even some minor details that would be visible may be either simplified or removed to make the model run better in a computer. So the models were manually simplified, removing objects inside the buildings that would not be visible but would have affected the app's performance. Furthermore, textures were added to the models to make them photorealistic.

Another issue to be noted with this pilot is that current building occupies mostly the same space as the virtual models of the historical buildings. It is not a trivial problem to virtually remove existing structures from an augmented reality view. If a virtual object is simply drawn in the correct location on screen when the real environment has something located in front of the virtual object, the virtual object seems to be closer to the observer and smaller than intended. The physical objects should be masked or removed in some way.

Some processing approaches for diminished reality

- **Clean plate compositing**, which means that most if not all of the surroundings would have been modelled and displayed, masking the current buildings. This would be about the same as presenting the historical quarter as virtual reality.
- **Diminished reality.** Means virtually removing some real objects from the AR scene. This can be a complex process, depending on the size and surroundings of the removed object. In this case practically everything from the current environment should be removed and replaced.
- **Distorting and colorizing the area.** In this approach the image structure of the current building is broken up and some smoke or mist-like effect is added to partially hide the building. This option was used in the app. The positive arguments for it are that it is relatively simple to do, it matches the light and weather—because the building is seen through camera—and there is no manual work needed.

LESSONS LEARNED

This is an example of a case where close cooperation between disciplines is needed. Architects, historians and archaeologists had to decide on interpretations based on all the available historical information. Ideally, the models could have been made as visualization models, instead of architectural models that required modifications. This would have required more communication between the modelling architect and software team, or the architect should have learned new skills to make visualization models.

The process was iterative, with checks and modifications made during the project, which is normal. In case a lot of buildings were to be modelled, it would be efficient to avoid the modifications phase, but in a single shot case the extra work done was probably smaller than training the architect to make visualization-optimized models.

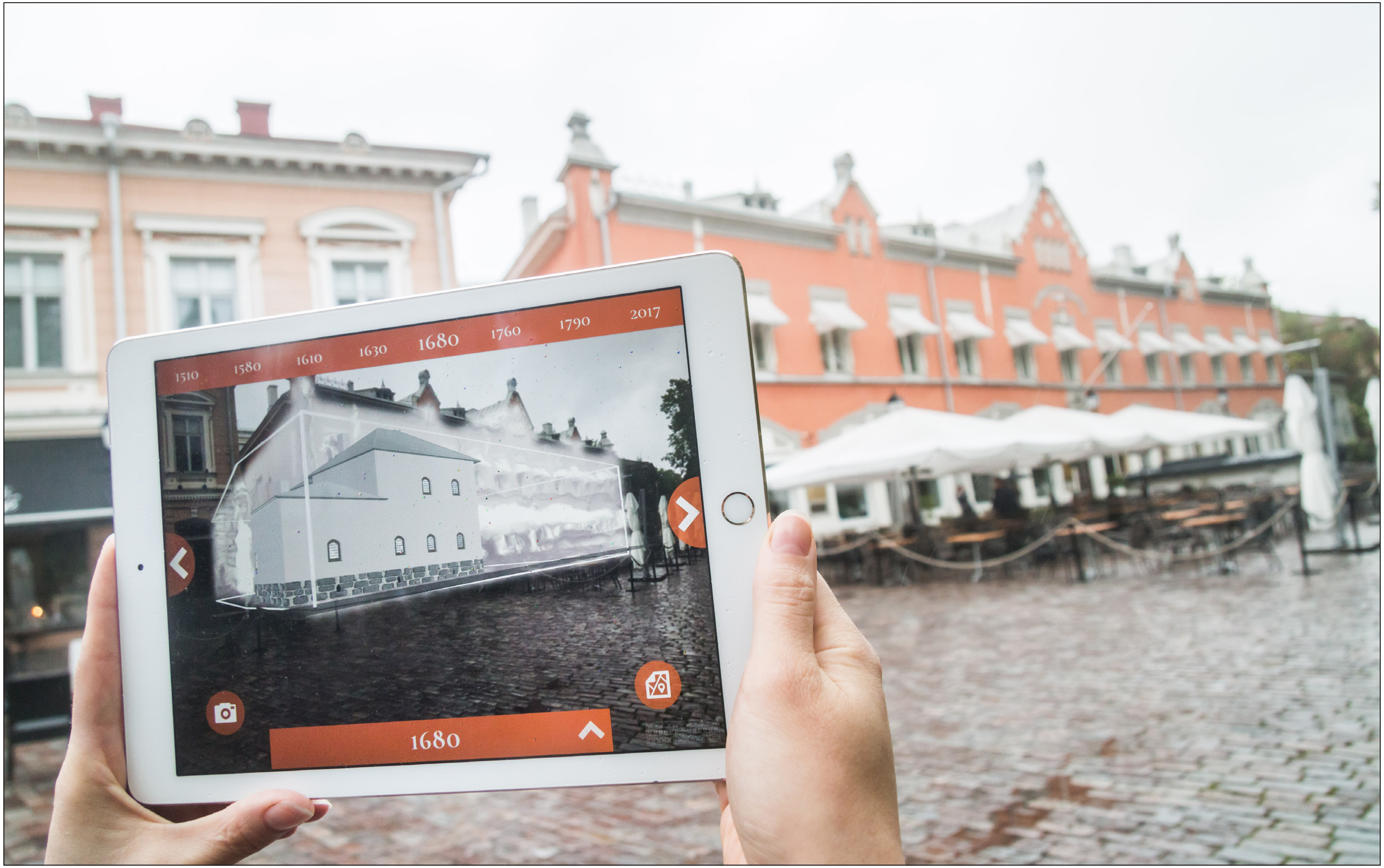


Image 1: House Casagrande app distorts and fades the current house in order to highlight the historical, virtual buildings.

4.6 CASE MOBILIA I—THE ROAD GRADER SIMULATOR

The goal of the pilot was to provide an embodied experience to museum visitors, and to study, how to support the feeling of immersion in a simulator environment by using novel input and output technologies. Inspired by the theme of the installation museum—automobile and road museum Mobilia (Kangasala, Finland)—a vintage road grader was selected as the theme of the simulator. The system has been available for museum visitors since June 2015, and subjective feedback from the users has been collected. The simulator has been improved based on the feedback, and the main changes can be divided into a first and second version of the simulator.

SYSTEM DESCRIPTION

The content of the installation is based on 4K resolution 360° video. While it does not allow users to drive around freely, 360° video was chosen because it is more cost-efficient to produce than 3D models, and a real vehicle was available for capturing realistic material. A camera setup capable of capturing full spherical video was attached on the roof of an actual grader, a microphone was placed inside the cabin and the grader was driven around small roads.

The current system setup of the simulator can be seen in image 1. It consists of a seat, a steering wheel and pedals, a computer, three projectors, an active audio speaker, and a set of sensors. The sensors are a 3D accelerometer and gyroscope for steering wheel (Yocto 3D), linear potentiometers for pedals (Yocto Knob), and light sensor for the seat (Yocto Light) to detect whether someone is sitting on it. The seat also has a device called Buttkicker to provide a strong vibration feedback.

The steering wheel movement is limited to roughly 65 degrees so a single sensor without moving parts is able to detect the steering. In the first version, the steering wheel rotation was unlimited. This was replaced because the user feedback indicated that it did not provide good experience and the implementation was prone to fail. Other major changes made for the second version were to expand video view from one screen onto three screens, and to provide a clearer visual response to accelerating and braking.

To create interactivity, the software

- Plays back in so-called small planet projection until a user sits down and the video animates to view directly ahead.
- Communicates speed controlled with pedals in three ways:
    - Video playback speed is full or half speed. Only two speeds are used to ensure reliable video playback.
    - Audio matches the speed. A selection of recorded sound clips with varying the playback speed is used both for audio and vibration via the Buttkicker.
    - Video image field of view varies so that high speed has narrower field of view than slow speed to emphasize the appearance of motion. The view also tilts so that in fast speed the camera looks more downwards, displaying more road near the vehicle, further affecting the experienced speed.
- Provides some feeling of steering by
    - Camera heading adjustment matching steering wheel rotation.
    - Virtual camera sideways position varies to small degree per steering as well.

The steering feedback has not resulted in a good enough feeling of control, and we are currently building a solution, where more realistic driving simulation is implemented. The 360° video allows projection ef-

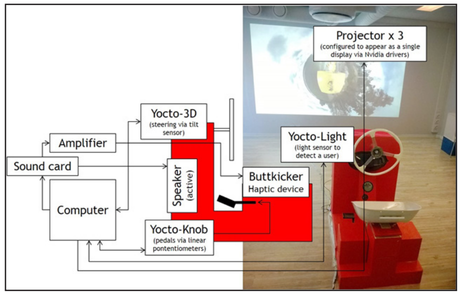


Image 1. The road grader simulator setup.

fects which can emulate actual driving within small area. This solution needs a video without a visible vehicle. Thus, a 3D model will be used instead. By limiting the steering to the width of a narrow road, we hope to create good experience with the limitations of the video material.

EVALUATION

In order to study museum visitors' experiences about the road grader simulator's different versions, subjective feedback from the users has been collected with a questionnaire.

Subjective data collection

Museum visitors' user experiences about the road grader simulator have been collected with a paper-form questionnaire. Because a suitable questionnaire was not readily available, one was created to correspond with the context, and the objectives of the system, and more broadly also the project. Thus, in addition to more general user experience aspects, the questionnaire had to inquire about immersion and appeal of the system in the context of a (car) museum.

The questionnaire includes ten statements with a five-step rating scale, which can be seen in image 2. In addition, the overall liking of the system is inquired with a five-step smiley face scale ranging from extremely unhappy to extremely happy. To support and explain the quantitative results, the questionnaire includes open-ended sentences inquiring the best and worst features of driving with the road grader, as well as a possibility to provide other comments. The questionnaire ends with a background information section asking the respondent's age, gender, personal interest towards technology (e.g., cars), playing and history.

Respondents

Overall, i.e., concerning the first version (from mid-June 2015 until early-January 2016) and the second version (from late-May until the end of 2016), we received feedback from altogether 187 respondents (84 boy/male, 58 girl/female, 4 other, 41 did not answer). The ages of the respondents varied between 1.5–68 years (mean=23.1, SD=17.8), the age group of 0–10-year-olds covering about 37% and 11–20-year-olds about 20% of the responses. The respondents were very interested in technology and history (medians 5/5), and somewhat interested in playing (median (4/5).

Results

Considering the first version of the road grader simulator, the overall feedback (n=92–104) was rather positive. For the question "How much did you like the road grader simulator overall", the respondents rated their experiences as 4/5 as a median on the smiley face scale. The respondents felt that the driving with the road grader was rather fun (median=4), and they totally agreed with the statement that these kinds of simulators would increase their interest towards museum visits (median=5). However, the respondents did not really feel as if they were actually steering a road grader (median=2), and they were rather neutral considering the statement "I felt like I was actually aboard a road grader" (median=3). One obvious reason for the respondents not feeling to be aboard a road grader might be that the camera was situated on top of the roof instead of the cabin when shooting the 360° video with the actual vehicle.

Installing the Buttkicker during the evaluation of the first version of the road grader simulator was a good choice. This change improved the experiences statistically significantly (Mann-Whitney U, $p<0.05$) considering the irritatingness and the funniness of driving with the road grader, the willingness to drive again, and the overall liking of the road grader simulator.

Considering the second version of the road grader simulator, a summary of the statement results as reported by the respondents can be seen in image 2.

Similarly as with the first version, the second version of the road grader simulator was received rather positively by the users. The median for the overall liking of the simulator was again 4/5 on the smiley face scale. The experiences regarding the immersiveness-related statements "I would like to drive again with the road grader", "I would like to tell my friend about the road grader", "I felt like I was actually steering a road grader", and "I felt I was actually aboard a road grader" as medians compared to the first version showed an improving trend. However, statistically significant (Mann-Whitney U, $p<0.05$) differences between the experiences about the first and the second version of the road grader simulator were found only considering the overall liking. Also, despite our efforts to improve the simulator, the lack of steering kept on being mentioned in the answers for the open questions. Thus, our work continues by implementing a version with a more realistic driving simulation.

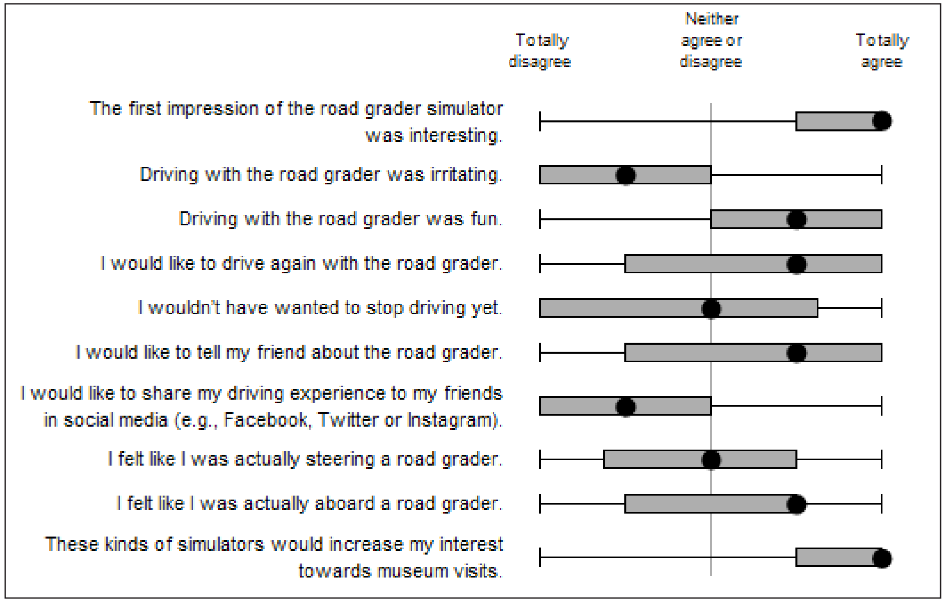


Image 2. Reported user experiences about the road grader simulator's second version. Again, the whiskers indicate the minimum and maximum responses, the gray boxes indicate the interquartile range, and the black balls represent the median values (n=66–71).

4.7 CASE MOBILIA II—THE 360° RALLY SIMULATOR

The goal of the pilot was to provide a pleasant, embodied experience to museum visitors by utilizing novel technologies. In line with the theme of the installation museum—the rally museum within the automobile and road museum Mobilia (Kangasala, Finland)—a simulator based on omnidirectional video and audio from real-world rally driving was created. The system has been available for museum visitors since June 2016, and subjective feedback from the users has been collected.

SYSTEM DESCRIPTION

The 360° rally simulator is a system built for Samsung Gear VR headset and Samsung mobile phones. It utilizes Oculus Mobile VR SDK for displaying the visual material on Gear VR. The simulator is built inside an actual rally car which is part of the Mobilia Rally Museum collection. Inside the car, the users are able to sit either on the driver's or the co-driver's seat, and while sitting on the driver's seat, also keep their hands on the steering wheel. The simulator application is used by putting on the Gear VR headset and separate headphones. See image 1 for the physical setup in the museum.

Image 1. In the 360° rally simulator installation, the user is able to sit in a real car and experience the rally stage through VR glasses and headphones.

The application consists of several omnidirectional videos and audio recorded inside a rally car during a winter practice stage by many times Finnish rally champion Juha Salo and his co-driver Marko Salminen. Some of the videos are interactive and some are just static videos which the user can experience. On top of the videos is an audio overlay, which is important in enhancing the experience, because it allows the user to listen to the pacenotes read by the co-driver during the rally driving. This combination of video, audio and actual physical car environment is designed to provide a novel and exciting experience for the user.

EVALUATION

In order to study museum visitors' experiences about the rally simulator, subjective feedback from the users has been collected with a questionnaire since the simulator's first deployment in June 2016.

Subjective data collection

Similarly as with the road grader simulator, museum visitors' user experiences about the rally simulator have been collected with a paper-form questionnaire. For consistency and comparability reasons, the questionnaire created for the road grader simulator was taken as the basis for rally simulator's evaluation as well. Because the objectives for both simulators were the same, only rather small modifications and additions were required.

For the rally simulator questionnaire, in addition to naturally changing the wording to refer to the rally experience, an item inquiring the respondent's physical seat within the car (driver's seat or co-driver's seat) and a statement inquiring whether the simulator caused the respondent nausea were added. Also, the inquiry about the respondent's personal interest in history was replaced with interest in rallying. The final 11 statements rated on a disagree–agree scale for the rally simulator can be seen in image 2.

Respondents

Between mid-June 2016 and mid-January 2017, we received feedback from altogether 256 respondents (134 boy/male, 84 girl/female, 2 other, 36 did not answer). The ages of the respondents varied between 4–70 years (mean=32.1, SD=18.1), the age group of 36–50-year-olds covering about 32% of the responses. A clear majority of 94% of those who reported their physical seat, sat on the driver's seat. The respondents were very interested in technique (median 5/5), and somewhat interested in playing as well as rally racing (median 4/5).

RESULTS

A summary of the statement results as reported by the respondents can be seen in image 2.

The overall feedback about the simulator has been very positive. For the question "How much did you like the rally simulator overall", the respondents rated their experiences as 4/5 as a median on the smiley face scale. The users have reported the rally experience to be extremely fun (median=5), and they would like to get aboard the rally simulator again (median=5). As the simulator did not attempt to mimic the situation of one actually driving a rally car, and the camera was situated between the driver's and the co-driver's seat, the respondents' experiences about the statement "I felt like I was actually driving a rally car" remained neutral (median=3). However, the respondents somewhat agreed with the statement that they felt like they were actually aboard a real, moving rally car (median=4). As with the road grader simulator, the respondents strongly agreed that these kinds of simulators would increase their interest towards museum visits (median=5). An interesting finding is also that the respondents totally disagree with the statement that the simulator would cause them nausea (median=1), although it is commonly known that 360-degree videos experienced with virtual glasses may cause nausea.

Considering the open-ended questions, the respondents admired the experience in general, the genuinity, i.e., as if they would have been aboard a real car, the possibility to sit in a real car, and the possibilities provided by the omnidirectional video, i.e., the ability to look around. Also the speed factor, and the audio and the pacenotes, were mentioned many times. The negative comments about the rally experience concentrated on the issues raised by the winter scenery throughout the responses: the video was too bright, and thus, the environment outside the car, and the road and its surroundings, were not visible. Based on this feedback received mainly during 2016, new material recorded in summer scenery was made available to the museum visitors in mid-January 2017.

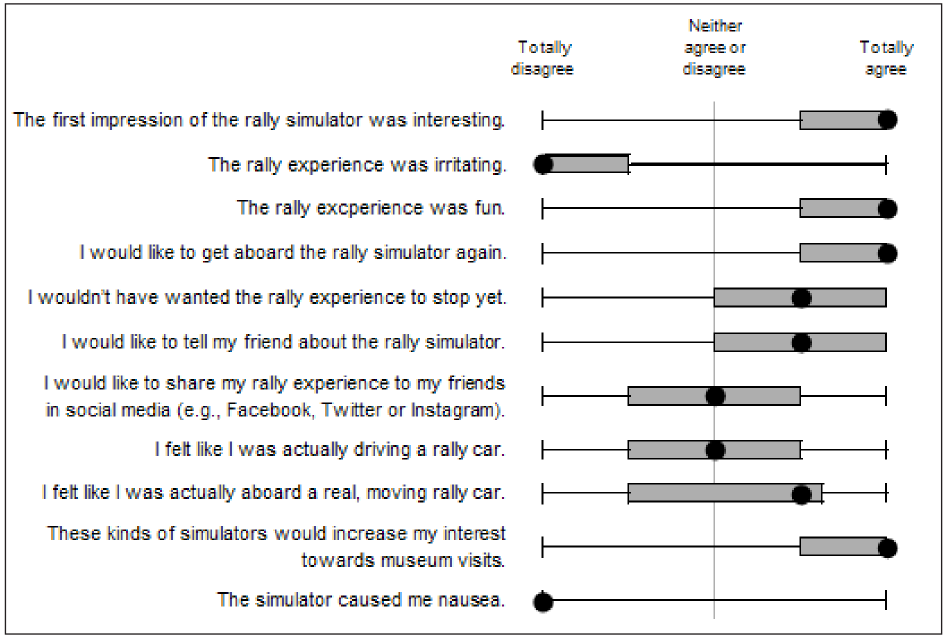


Image 2. Reported user experiences about the rally simulator. The whiskers indicate the minimum and maximum responses, the gray boxes indicate the interquartile range, and the black balls represent the median values (n=227–241).

4.8 CASE VAPRIIKKI—THE OPTICAL TELEGRAPH

The goal of the pilot was to study how novel input and output technologies can be used to enhance museum goers' experience, and how gamified content works in a fixed augmented reality installation. We decided to create an augmented-reality, interactive version of the shutter telegraph invented by Abraham Niklas Edelcrantz in the 1800s. The interactive replica would then become part of the new Rupriikki media exhibition inside the Vapriikki museum (Tampere, Finland).

The intention behind the installation was to demonstrate to users the operation of telegraphs through a hands-on experience. In this way, museumgoers could obtain a deeper understanding on how the communication worked with such apparatuses and enhance their visit beyond the mere learning historical facts. However, when chatting with "von Edelcrantz", the history of telegraph as well as Edelcrantz's biography and his background close to royal court in Stockholm revealed to the visitor with a playful manner.

The installation is presented as an optical telegraph tower printed on a veneer plate. However, in practice, it simulates two towers, a local tower where users can send messages to a remote tower and a remote tower that communicates back with the user. Image 1 shows a schema of the final installation and its different components.

The upper part of the veneer plate is augmented using a projector and it represents the remote tower section. The purpose of this tower is to display the incoming communication from the remote interlocutor. The communication is shown as moving shutters that turn to create different kinds of message codes, in the same manner as the original telegraph would. Additionally, each shutter contains a numerical value—used for codification purposes—to help users to deduce the logic behind the message codes they receive.

On the lower part of the veneer installation, there is a representation of the local tower section; it comprises a built-in monitor, some switches and buttons utilized for user interaction. The monitor shows a virtual representation of the local tower, which can be controlled by using multiple switches to change the states (ON or OFF) of each shutter. In addition, the screen displays some additional information such as a biography from the telegraph's inventor and the local tower's codebook. Moreover, a chat history is presented on the screen where users can see the messages they have sent and received, allowing them to keep track of the conversation.

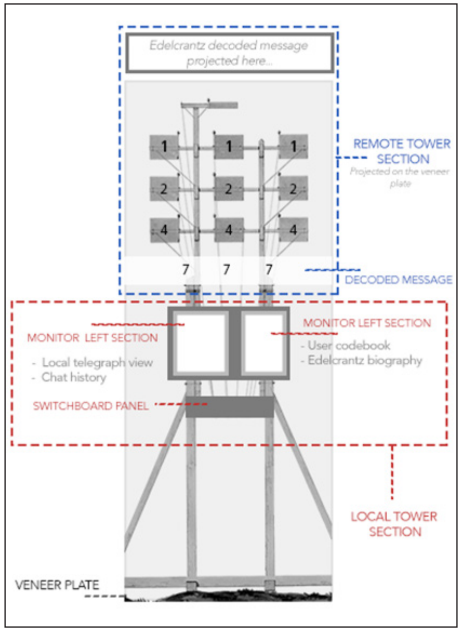


Image 1. Schema of the installation.

TECHNICAL SOLUTION

The system comprises three main components:

The Core Module: A Node.js, HTTP server that hosts the web application. This module handles the switch interaction from users and the communication with the Chat bot module.

The Chat bot Module: A Node.js module that synchronizes the communication between the chat bot service and the core module.

The Chat bot Service: A Python-based artificially intelligent agent that generates language responses according to the messages received from the user. In addition, the service invites museumgoers to interact with the system by constantly greeting them while there is no one using the exhibition.

USER TESTING AND FEEDBACK

The installation was evaluated during observation sessions, experience questionnaires and interviews. Three observation sessions were held during the museum night 2016 and on the museum's birthday weekend in October 2016. In these sessions, users were approached after using the system and prompted to fill an experience questionnaire and answer the interview questions.

The experience questionnaire comprised a series of statements regarding the interaction and experience using the telegraph as well as some other background information concerning the users' interests. Each statement was assessed using a five-point Likert scale (1=Totally disagree, 3=Neither agree nor disagree and 5=Totally agree). The overall impression of the system was rated using a 5-step smiley scale.

Image 2. Final installation.

The questionnaire statements were

- The first impression about the telegraph was interesting.
- The idea of the telegraph was clear.
- The telegraph was irritating.
- Communicating with the telegraph was fun.
- I would like to communicate with the telegraph again.
- Sending the messages was easy.
- Figuring out the coding principle was difficult.
- The application helped me to understand the principle of the optical telegraph.
- The application taught me about the telegraph's history.
- These kinds of applications would increase my interest towards museum visits.
- I would like to tell my friend about the telegraph.
- I would like to share my coding experience to my friends in social media (e.g., Facebook, Twitter or Instagram).
- I am interested in playing.
- I am interested in problem-solving tasks.
- I am interested in technique.
- I am interested in history.
- How much did you like the telegraph installation as a whole?

The answers from a total of 54 respondents were analyzed. Museumgoers had a good impression of the system, which can be evidenced in a high general score of the installation (median=4). Additionally, users expressed that the communication was fun (median=4.5) and indicated that the telegraph was not irritating (median=2). Moreover, users found the idea behind the telegraph clear (median=4) and their ratings for the level of difficulty ranged in the middle, as can be seen in the answers regarding message emission difficulty (median=3) and the code-solving difficulty (median=2).

Participants also stated that they would like to communicate with the telegraph again (median=4) and that they would recommend the installation to friends (median=4). Furthermore, they considered that the application helped them understand the telegraph's operation (median=4) and history (median=4). Additionally, visitors strongly agreed with the statement that installations such as the telegraph raise their interest in museum visits (median=5).

OBSERVATION RESULTS

During a weekend observation, museumgoers who passed and interacted with the installation were observed and tallied. A total of 267 passersby were tallied amid the observation weekend of which 49% noticed the telegraph and 27% started interacting with the telegraph installation.

Users' information

Besides the passersby information, additional details were noted down about users who interacted with the installation. Such details include their estimated age, gender, and the type of user. From a total of 178 observed users, 44% were male and 56% female. The age distribution of 176 of the users shows that the largest number of users corresponds to young adults and adults with ages ranging from 19–29 (29%) and 39–59 (29%), respectively. Followed by teenagers from 12–18 years old (21%) and children under 12 years old (20%). Finally, only 1% of the users were 60 years or over.

LESSONS LEARNED

The remote tower projection acts as a nice point of attraction to catch the attention of people passing by. However, it is rarely used while users are interacting. The reason for this is possibly that the projection is located right above users, which makes it uncomfortable for them to look up to see the remote tower.

The switches were also successful in catching attention and attracting users. Additionally, some users expressed that it was their favorite parts of the telegraph. They mentioned that the sounds and the feeling of moving the switches was a nice element of the installation.

Switches can provide limitations in the system design. Because of their physical constraints, they cannot be reset to an initial status, which means that users will start using the switches in the state the last user left them. In the Vapriikki installation, it may affect the problem-solving tasks that users had to go through since the initial state of the system could give hints or make it more difficult.

4.9 AMOS ANDERSON

OVERVIEW

During the Miracle project, building of new facilities for Amos Anderson Art Museum began at the center of Helsinki. Building site is located in an area with one of the highest density of daily pedestrian traffic in the city. The interest from the museum staff to investigate how mixed reality could be used directly at the building site to increase people's interest and awareness of the building project was the main goal set for the pilot.

Based on discussion between museum staff and VTT researchers on various approaches how mixed reality technology could be combined with the museum building project, an approach of using optical see-through display setup to augment a view to the construction site through a construction site fence was chosen as the main technical approach to be used in the pilot implementation.

After the initial decision of technical approach to be used, the development of the content and technical implementation were carried out in an iterative manner brainstorming content and testing of technical feasibility in collaboration with the museum staff. Planning of the pilot system implementation as a public installation within the construction site required also coordination between construction site management, builder of the pilot installation structure and PR agency designing the overall look of the visual elements used at the building site.

In the final pilot, the director of Amos Anderson Art Museum, Kaj Kartio, is present at the building site as a statue that is brought to life with the help of augmented reality. The pilot system is aware of the viewers looking at the construction site with the statue through a viewing hole in the construction site fence. Based on the detected viewer presence, the pilot system drives the content clips where museum director introduces various aspects of the building project. Goal is to create a feeling of a living status that is aware of the viewer and engages a discussion directly with the viewer.

Installation of the final pilot system begun on-site began at the end of September 2016. Pilot remained operational from end of September to mid-November, during which time also user feedback and statistics of the use were collected.

IMPLEMENTATION

Implementation consists of the physical construction of the display setup, physical statue, computing hardware and software. Optical see-through display is created with a combination of a high luminosity display and a half silvered mirror which operates as a beam combiner overlaying the image on the display to the view the user has through the half silvered mirror to the physical statue placed into the construction site.

Installation uses several USB-cameras to inspect the area in front of the installation in order to detect people using computer vision analysis. Software used by the installation triggers content clips according to the presence of viewers. Approximated location of viewers estimated from the captured camera images is used for controlling the gaze direction of the eyes that area rendered on the display and overlaid on top of the statue.

Bust of the museum director Kaj Kartio used as a statue in the installation is produced by 3D modeling the shape of the head initially captured as a 3D scan. 3D model is 3D printed with a plaster printer and processed to withstand the outdoor environment conditions. Content clips are video recordings of performance by Kaj Kartio. Post-processed and masked video clips are displayed with the optical see-through display so that the location and accommodation distance matches with the statue as seen by the viewer. Aligning of video capture of live performance together with the statue causes video image to fuse together with the view the user has to the statue, thus creating an illusion of statue being alive rather than seeing statue and overlaid video image separately.

Reaction to viewer presence and use of gaze direction control to create an eye contact between viewer and statue used by the installation enhance the experience, creating illusion of personal conversation and intimacy. This personal feeling of communication increases the attention and engagement of viewers and improves the distribution of message contained in the augmented reality content.

USER EXPERIENCE

User experience about the usage of the installation was collected by UTA with a paper-form questionnaire. Collection was done as a one session, during which time the installation was in normal operation mode and users were passing by the installation with no prior information given. In summary, the feedback collected from the users' displays a positive evaluation of the experience, 87,5% of all users grading experience to be either good or very good.

COMMERCIALIZATION

Introduction of the pilot case results led to a design of a simplified 'Talking head' installation in discussions together with the staff of Museum of Kymenlaakso. With the simplified installation version, a human character is printed to a scale on a cardboard material integrated with a tablet device. Tablet device display is used for displaying eyes for which holes are cut to the cardboard character. Tablet device is monitoring the area in front of the printed character with the embedded camera of the tablet device. From the captured camera images people are detected and audio content and eye gaze direction are controlled accordingly. First iteration of the simplified installations were manufactured and installed at the Museum of Kymenlaakso at the end of 2016 as part of the 'Kasvoja Kymenlaaksosta 'exhibition.

Image 1: Prototype of the installation being built and tested

Image 2: Building of the installation at the final location in construction site

Image 3: Installation integrated with the construction site fence as a viewing hole

Image 4: Augmented statue as seen in with the installation

4.10 MARITIME CENTRE VELLAMO / SELFIEWALL

OVERVIEW

A new exhibition of Museum of Kymenlaakso was opened in Maritime Centre Vellamo, Kotka, in fall 2015. Together with the new exhibition, the museum expressed their wish to create a high impact interactive installation which would allow museum visitors to "become part of the history". As result of workshops with the museum personnel, VTT produced a concept of implementing an interactive large scale display that would augment viewers as seamlessly as possible to historical photographs, and sharing the photos in social media.

IMPLEMENTATION

The first implementation was completed by time of the new exhibition opening. The system consists of a large 2x2 screen display, installed at the entrance of the museum space. Visitors approaching the scene are separated from the background, based on depth camera technology. This enables the visitors to be augmented into the photos as being part of it. Some dozen different historical photos were chosen as the content, displayed as a continuous reel.

The photos are segmented in different layers so that the users can see themselves e.g. behind different photo elements. The users are transformed in the same perspective with the photos, and also the color characteristics of the users are tuned to match the photo appearance, e.g. black & white, graining, lighting etc. Several visitors can be simultaneously augmented in the photos. Altogether, the application creates a surprising and delightful experience when entering the museum space, and encourages playful interaction and personalized experience with the layered photos.

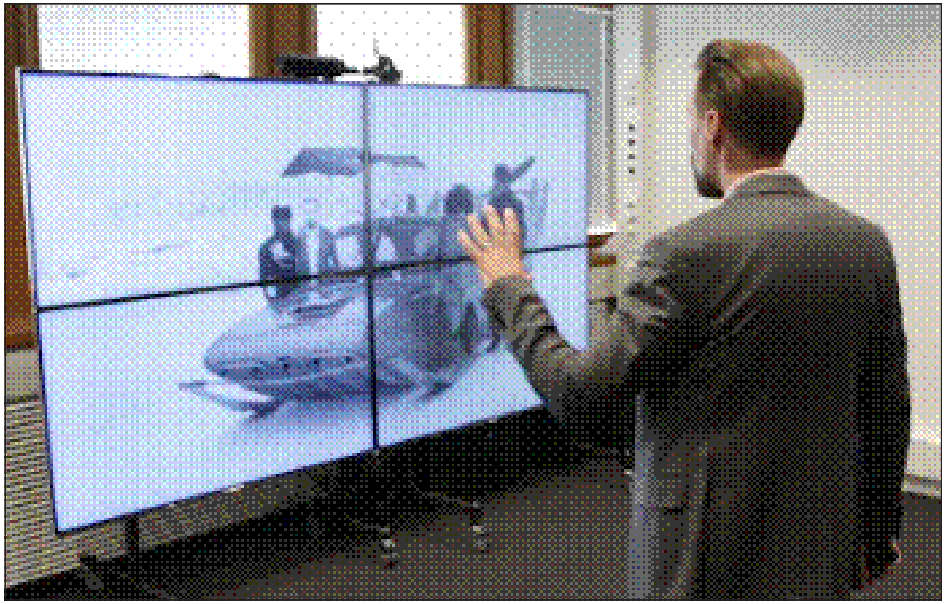


Image 1: SelfieWall system with 2x2 screen.

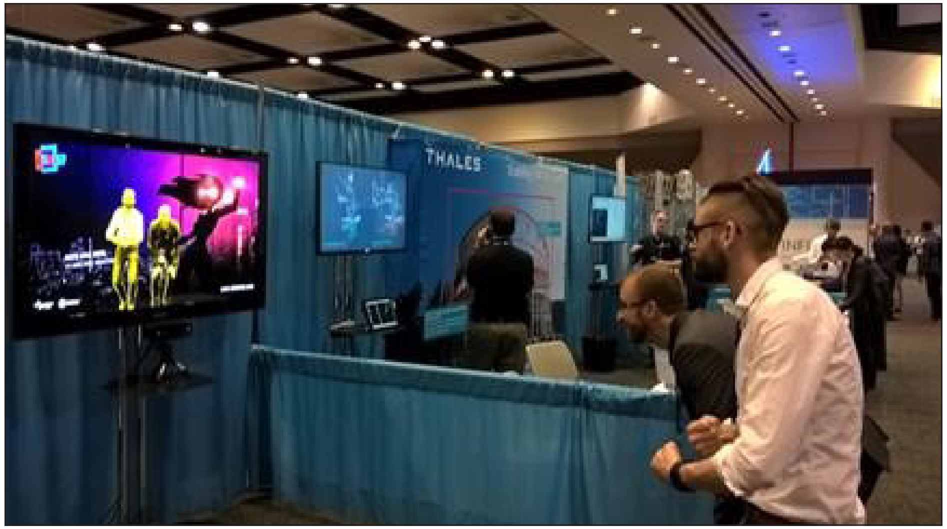


Image 2: SelfieWall at AWE2016 exhibition, Silicon Valley, USA.

USER EXPERIENCE

User studies of the visitors were conducted by Helsinki University. In summary, the study revealed that over 50% of visitors spent over two minutes interacting with the system. Overall the installation can be considered as a big success, fulfilling very well the museum's original expectations of engaging the visitors with the museum content. Later on a second system was installed at another exhibition at Vellamo.

COMMERCIALIZATION

The system was coined by the museum as "MiracleWall", or "IhmeSeinä" in Finnish. Subsequent development of the system has taken place in an EIT Digital funded project StreetSmart, under name "SelfieWall". The system has thereby gained lot of commercial attention and new customer segments also in new applications such as advertising, by way of immersing people into brand related photos.

SelfieWall customers in Finland include ClearChannel / Itis, Kulttuuritalo, HOK / Ateneum and Kansallisooppera / Kirjamessut. As the first international customer, Autodesk Inc. ordered two SelfieWall licenses in January 2017, one as permanent installation at their technology museum in San Fransisco and another one for exhibition tours around the continent.

Patent application of SelfieWall was filed in spring 2016.

Video of press release by VTT: *https://www.kauppalehti.fi/uutiset/selfie-seinalla-voi-sukeltaa-keskelle-menneisyytta/kjnAPDBw*.

Image 3: SelfieWall and Kullervo painting at Ateneum, Helsinki.

4.11 MUSEUM OF TECHNOLOGY / AUGMENTED RADIO WAVES

OVERVIEW

A new exhibition "Etäunelmia"—history of electronic communication—was opened in Tekniikan museo, Helsinki, in fall 2016. As general goal for the MIRACLE pilot, the visitors should be provided with new kinds of memorable experiences and insight into the exhibition, including ways of understanding how the technology works, enhancing the learning experience by "seeing the invisible", and linking the exhibition items together under a general visual theme.

The museum people came up with the idea of augmented visualizations of electromagnetic waves being transmitted and/or received by different devices in the exhibition. The user may view the museum exhibit devices and see the related electromagnetic waves simultaneously augmented, or select certain devices or wave frequencies from the system's user interface. The waves are visualized in an interesting and instructive fashion.

IMPLEMENTATION

The pilot system is now available for general museum visitors on the upper museum floor. It is implemented on a large screen on a fixed podium, with possibility to move the screen around to augment different devices at the exhibition area. Also a mobile version of the system was implemented on a tablet device, but it was not made available to general audiences.

The application is designed to be equally interesting to all visitors, however school students being a special target group. The motivation is to extend from traditional wave theory presentations to more sophisticated and easily memorable visual methods, and link different waves to real physical objects at the exhibition. This will support understanding and learning of the wave theory and its relations to different devices.

The visualized data is pre-defined based on the devices in the exhibition. The target devices (e.g. mobile phone, radio, television)

Image 1: Pilot system at Museum of Technology.

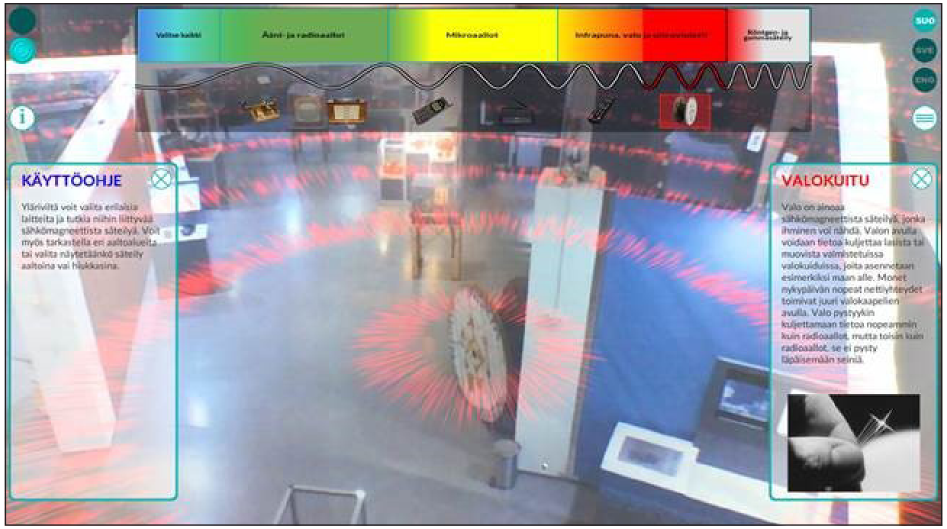


Image 2: User interface and augmented radio waves.

have their own wave lengths and properties. These waves are mapped in visual light range and shown in augmented reality on the screen. The user may change the visualization by selecting desired wave spectrum or only wave source. The user interface to select the devices and wave lengths was designed to be as self-explanatory as possible. A student should be able to use the system with only minimal guides at start of the application.

RESEARCH CHALLENGES AND RESULTS

The application field is novel and the implementation provided several design choices on user interface and usability. A special research item was the rendering, how to visualize the invisible? The nature of electromagnetic waves makes the visualization very challenging. The visualization must support the textbook theory but should also visualize the waves in real environment in an interesting fashion. The final pilot implementation seems to solve these research questions as well as the original requirements well, having potential also for wider adoption at similar exhibitions around the world.

Video of the application is available at:
https://youtu.be/YhbbiJ972UY.

4.12 ILMAILUMUSEO / HOW TO FLY

OVERVIEW

The Finnish Aviation Museum ("Suomen ilmailumuseo") is renovating its' exhibitions and planning a brand new museum building in Vantaa Airport area. The key issue is the development of the audience relations and especially cooperation with the schools, teachers, and school administrations. The main goal was "bridging the gap between formal education and informal learning"; e.g. giving opportunities for out-of-school education.

The content of the "How to fly" AR-solution was strongly supporting the curriculum of the Finnish comprehensive school. Especially the New Curriculum (OPS 2016) is demanding the use to apply "PBL-Phenomenon Based Learning" ("Ilmiöoppiminen"), and this How to fly –case gave fruitful opportunities for the teachers.

The application was also presented for greater audiences in the "Suuri Lentonäytös 100 v Suomi", June 9th 2017, the biggest air show in Finland.

IMPLEMENTATION

"Mixed reality" was the key word of MIRACLE. The "How to fly" –application was really putting together a) Augmented Reality; b) the mechanical equipment (real science test model The Wind Tunnel), and c) the learning and use took place in the exhibition context surrounded by real objects as mainly airplanes.

How to fly Air wing application demonstrates how air moves around the airplane wing and what kind of forces it creates to the wing. It also shows how air moves around different shapes such as cones and spheres. It was implemented on Android platform using Unity game engine. Several augmented reality toolkits were used during the project, including ARToolkit and Vuforia. First implementations relied on Unity physics engine but it had performance limitations. A Unity editor plugin was implemented so that we could easily create dynamic three dimensional trajectories for the air particle flows.

Augmented reality toolkits were

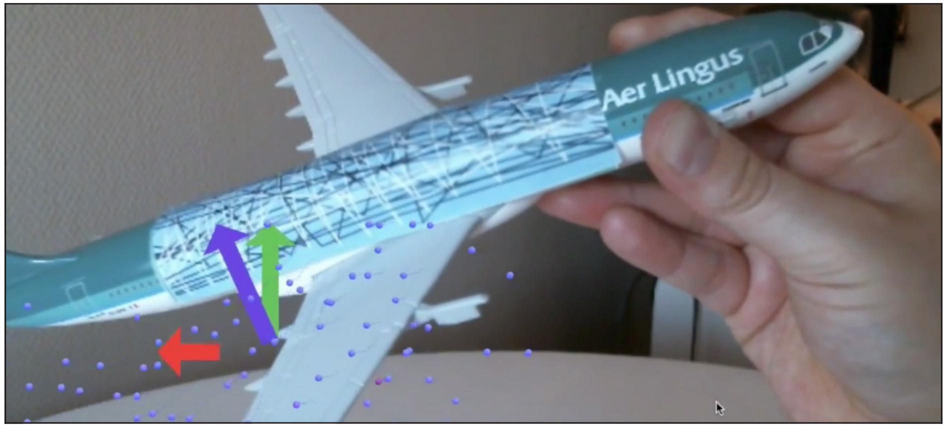


Image 1. Augmented reality demonstration of airflow and resulting forces on a model aircraft. The location and orientation of the model are observed from the graphics on the model aircraft's body.

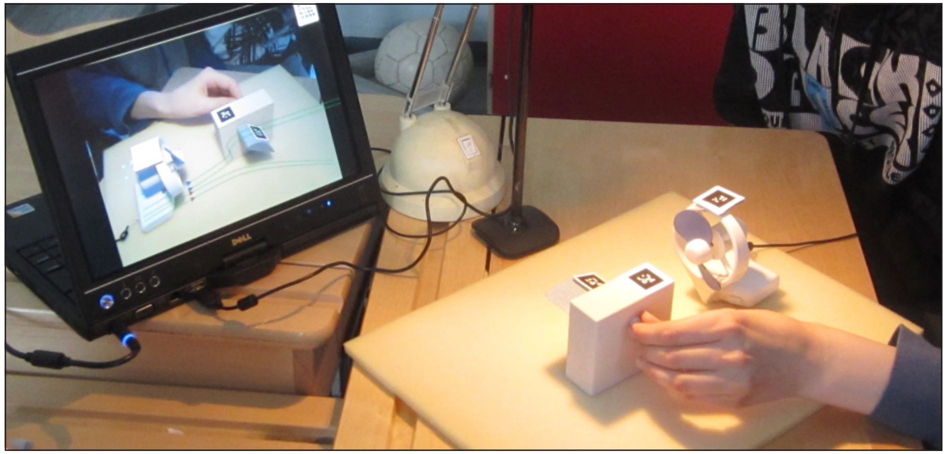


Image 2. An AR demonstration consisting of a fan and an adjustable miniature wing was used as pre-material before a museum visit. Airflow is visualized on the computer screen.

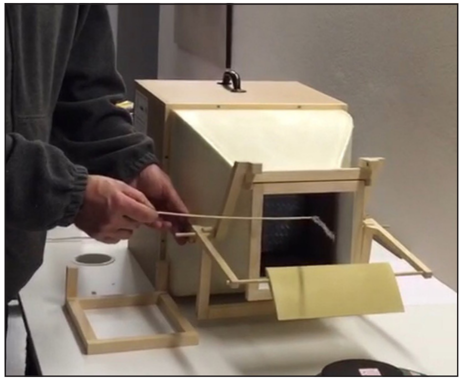


Image 3: The real scientific research equipment, The Wind Tunnel, created by the von Karman Institute, was used in the demonstrations

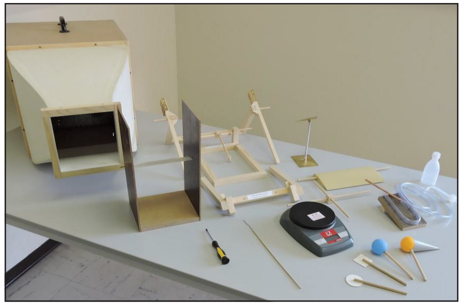


Image 4. The portable wind tunnel can be packed into cases for transport. The hand-held tools on the foreground can be used to demonstrate the effects of airflow on different shapes.

used to find the angle of the airplane wing so we could calculate the airflow trajectories. A hidden three dimensional wing model with depth mask shader was used to create an illusion where airflow could be hidden behind the wing seen in the camera feed.

The mini-wing demonstration was used in the Science Show, which was given to all pupils who visited the exhibition. The demonstration lasted 30 minutes in the beginning of the visit. Also the wind tunnel was utilized in this presentation.

How to fly –demonstration was utilized also as a tablet version. Pupils could use it while roaming in the exhibition among tens of different real airplanes.

RESEARCH CHALLENGES AND RESULTS

The research project related to "How to fly" was analysed in order to get evidence about learning using Augmented Reality (AR) technology and the motivational and cognitive aspects related to it in an informal learning context. The 146 participants were 11–13 year old Finnish pupils visiting the Aviation Museum. The data, which consisted of both cognitive tasks and self-report questionnaires, were collected using a pre- post-test design and were analysed by SEM path-analysis.

The results showed that AR-technology experience was beneficial for all, but especially for the lowest-achieving group and for the girls. In general, pre-knowledge skills predicted post-knowledge test results. As expected, school achievement had an effect on pre-knowledge results. In addition, motivation turned out to be an alternative key route for learning. Being a boy predicted directly or indirectly all other motivational variables, enjoyment and interest, but girls had a higher relative autonomy experience (RAI). Situation motivation and attitude towards learning in the science exhibition were much more strongly inter-connected among boys than girls, and attitude predicted post-knowledge only for boys. AR seems to be a promising method by which to learn abstract phenomena using a concrete manner (see also[1]).

REFERENCES

1. *Salmi, Thuneberg & Vainikainen (2016). Making the invisible observable by Augmented Reality in informal science education context. International Journal of Science Education, http://dx.doi.org/10.1080/21548455.2016.1254358*

4.13 MOLECULE MOVEMENTS

OVERVIEW

The pupils used the AR-application "Molecule Movement in Gas", which enabled them to see something more than is possible by ordinary experiments. While investigating thermal motion the velocity of molecular nitrogen for example in a refrigerator or on a hotplate can be compared both by following the motion of augmented molecules in different places and also by comparing the different velocities of the molecules on a temperature-velocity graph.

IMPLEMENTATION

Molecule Movements application displays real time temperature measurements using bluetooth connected wireless thermometer. The application was implemented on Android platform with Unity game engine. Unity physics engine was used to create the particle movement. Several different augmented reality toolkits were investigated during the project, including ARToolkit and Vuforia. A native Android Java plugin was written for Unity to communicate with the wireless ETI BlueTherm temperature probe. The biggest technological challenge was not related to augmented reality at all: It was to overcome the bluetooth connection errors and to create a robust application with a good user experience.

RESEARCH CHALLENGES AND RESULTS

The role of the digitalization in teaching is rapidly growing. Along with that, adapting of the augmented reality (AR) is becoming more and more common at school and therefore its study within the formal and informal learning context is important. Participants of the AR-study were 416 sixth-graders. They used the AR Molecule Movements at the science center. By the SOM-clustering analysis the aim was to identify subgroups of the students and supplement earlier results. The students using AR in science learning were clustered based on reasoning, motivation and science knowledge results. Earlier it had been noticed that after the AR-experience the science test results generally improved, but most of all gained the students with lowest achievement. The cluster analysis supplemented this by identifying a boy majority group in which the students were especially interested in science learning both at school

Image 1: Digital AR-thermometers—first and second version—developed to show the molecule movement's speed in different temperatures

and at the AR-applying science center. In spite of the low school achievement their high motivation led to good science learning results subsequent to the exhibition. The earlier results, according to which the girls closed the science knowledge gap between boys after using AR, became more relative, as two girl-dominated subgroups were identified. In the other the students were motivated, however the wrong answers increased; in the other the students were highly uncertain and after the AR-experience there was no change. Possible reasons were considered on the basis of motivation and concept formation theories. The clustering results complemented earlier findings of AR-gains in learning.

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2. *Salmi, H., Sotiriou, S., & Bogner, F. (2010). Visualising the invisible in science centres and science museums: Augmented Reality (AR) technology application and science teaching. In N. Karacapilidis (Ed.), Web-based learning solutions for communities of practice. (s. 85–208). New York, NY: Information Science Reference. Hershey. ISBN 978-1-60566-711-9.*

5. SUMMARY

This chapter crystallizes the results of the MIRACLE project into a compact set of observations and guidelines.

Effective attractions

Many people find services and applications based on mixed reality technologies very interesting. Overall, the pilot applications developed within the project got mostly positive comments from the audience.

To maintain the interest, the subject and content must be interesting in itself. New technical gimmicks only attract for a moment, so great attention should be paid to the story and the actions the user can do within the app.

To make the most of the possibilities of mixed reality, consider these potential advantages of MR and think how they could be realized in your case

- MR can be used to explain and visualize many phenomenons, even complex ones. Are there such in your case? MR can result in efficient learning, especially for persons with a low achievement level.
- Add life, interactivity, action to the usually still museum environment. Think what could be done to make the experience with your case more active and lifelike.
- Offer alternative stories and interpretations. In many cases there's something about the history that we can't be absolutely sure—it might have been this way or that way. Would it improve the visitor's experience if you described more than one possible interpretation? This is easy to do with virtual content.
- Allow access to a lot of information, no matter what the physical space limitations are. With the help of a portable device, all the information the visitor will get needs not to be put physically into the exhibition room. Give the visitor more info about things that are of interest to just him/her. Offer guidance in more languages than just the usual three. Let the visitor get access to all kinds of related information in the web.

Many experts, good cooperation

- MR project often require cooperation between experts of different areas. How well it goes has a great effect on the outcome of the project.
- Make the cooperation between experts of different areas as easy and immediate as possible. The more the people can communicate the better, and the better the people know each other the better the outcome.
- Experts of one discipline should know enough about the requirements related to other disciplines in order to provide results that will advance the production. Historians should know some technology, and technology experts should understand the essentials of the content that is to be presented.
- Consider what tasks can be done by the "in-house" personnel, and what must be purchased from outside. Appropriate tools allow some tasks that would otherwise be done by technical professionals to be done by the local personnel.
- Be prepared for an iterative process that may take time. Make the schedules so that there is time for solving some unanticipated problems or making redesigns. Especially when people are working together for the first time there may be things to clarify to each other, and all that takes time.

Get the audience involved

- Communication technology, and especially social media channels, can be used to make the general people do things together and in cooperation with the professionals.
- When the general audience is supposed to have valuable stories or other information to be recorded and shared, you could get them involved by means of social media or tailored services. The application created to be a guide for a site can also contain functions enabling communication between people. Visitors may want to share their experiences with others, and they may be able to bring in something that can be added to the general offering at the site.
- Communicating and forming communities around various topics can also have societal effects. Sometimes this may be the main target you're after.

What could go wrong?

It isn't easy to guess in advance where the problems will be. But some potential risks can be predicted and avoided—like these ones.

- Using an app the visitor may forget the reality around. The result may be that the visit isn't as full an experience as it could be. Or worse: the visitor might stumble on things and cause harm to him/herself, other visitors or exhibits. To avoid this, the applications should be designed so that they do not require constant concentration on the device.
- Holding a device up front is also tiring. Even though the phone or tablet would be light, just holding hands up will be difficult after a while. To avoid this, the application should not require constantly "looking through" the device. Scene durations should not exceed some tens of seconds to keep usage comfortable. In some cases it is possible to let the user freeze the view and then use the device in a more comfortable position, continuing to observe the details on screen and getting more information.
- Visitors using an app may disturb others around. Paths may be blocked by app users, and noises coming from apps may be disturbing.
- The locations where the app is supposed to be used should be away from main pathways. Augmented reality tracking and rendering may run into problems when there are a lot of people in the area where virtual content should be, so the locations and directions of AR activities should be where heavy visitor traffic is not expected.
- Sound design should be done considering the possible disturbances. In some cases the sounds could be offered only via headphones, and where speakers are used so that the sounds will be heard by other visitors, the audio should preferably be subtle.

Technical and usability problems can spoil the experience. Generally it can be said that the experience is as good as its weakest part.

- With cultural travel applications tailored for individual sites, a large portion of the usage session will be by first-time users with the app. Therefore it is important to assist the user getting started with the app. It may be done in many ways, like tutorial screens, videos, printed instructions on the site or even personal assistance. It should just be there to make sure the users won't get stuck with the app when they give it a try.
- It is also a good idea for the application to give hints whenever it seems the user has problems proceeding. Tell what to look for, make the essential control functions obvious and easy to notice.
- Tracking problems may occur fairly often, at least with current technologies. The app should be able to detect situations where tracking doesn't work properly, and let the user choose an alternative solution. For example, a 360 degree video clip can be offered instead of the AR view.

Keep it going

Making an app may be fairly easy, but keeping it alive for an extended period of time probably isn't. Software platforms and operating systems are frequently updated, new product generations are launched with new features, and even new product categories appear on the market. All this may cause some functions and products to become obsolete—either the app may not work any more, or something in it is considered out-of date.

This is less of a problem for limited time cases, like apps for a specific exhibition that will be over after a few months. But often museums plan their exhibitions to go on without major updates for several years, and in such cases the need for software updates may become evident. This should be taken into account already in the planning phase of an application.

- If the plan is to have the app running for at least a few years, there should be a plan about financing the software updates that could be needed. Even for shorter usage periods an update plan would be a good idea, as it is common to find something to fix in the app after it has been taken into wide use. The plan may also contain more or less continuous content updates, which don't require changes in the actual application.

- When it seems probable that there will be new kinds of products on which the app could be used in the future, it is worthwhile to design the application concept and architecture so that it is possible to make new variants without writing everything from the scratch.
- To keep users' interest up, the content of the application should be flexible: people will have a better experience of a revisit if the application shows something new instead of repeating everything exactly the same way as the first time.

6. TOOLKIT

The Toolkit is a collection of software applications and components for mixed reality production. All these tools have been tested in the MIRACLE project; some are written in the project and published as open source software. Everything chosen in the Toolkit are low budget, free or open source tools suitable for production by multidisciplinary teams with limited resources.

Shown costs are dated 7/2017.

UNITY

https://unity3d.com

Game engine, a development environment for real-time applications originally targeted for game developers but recent additions in functionality target more wider user groups such as animated movies. As it is made to handle varied 2D and 3D content, it is a platform well suited to mixed reality applications. Deploys applications for all popular mobile, desktop and console platforms.

Cost
Free for non-commercial use and limited commercial use, reasonable subscription-type licenses available when used for commercial applications.

ALVAR

http://virtual.vtt.fi/virtual/proj2/multimedia/alvar/

ALVAR (A Library for Virtual and Augmented Reality) is a suite of products and libraries for creating virtual and augmented reality applications, developed by the VTT Technical Research Center of Finland. Library includes a high-level application programming interface (API) and several tools to create augmented reality applications. Low-level interfaces also make it possible to develop custom solutions.

ALVAR has been used as the tracking technology for many pilot applications in MIRACLE. It offers both 2D marker or image based tracking and markerless, point cloud based tracking solutions.

Cost
Reasonable per developer licensing model.

BLENDER

https://www.blender.org

Widely used 3D modeling and animation package with a variety of features. As a general 3D application it has steeper learning curve than specific beginner-friendly software (e.g. Marvelous Designer). Fast to use once learned and has plenty of learning material freely available, including tutorial videos. Contains tools for modelling, rigging, animating, sculpting, texturing and more. Comes with a built-in Python interpreter for tools programming and extending functionality.

Cost

Free and open source.

ARTICY:DRAFT

https://www.nevigo.com/en/articydraft/overview/

Articy:draft is a visual environment for the creation and organization of game and story content. It is designed for creation of non-linear storylines, branching dialogues, level layouts or character and item databases. Content can be exported into various formats—including JSON, XML and Microsoft Office. Content can be integrated into Unity with the comprehensive articy:draft to Unity plugin.

Cost
Free trial, different license models, also educational discounts have been available.

MARVELOUS DESIGNER

https://www.marvelousdesigner.com/

A tool for designing for 3D virtual characters and objects by familiar concepts of cutting and sewing. 2D clothing patterns are simulated on top of 3D objects for realistic folds and looks. Basics are learnable in a few days allowing quick start in the clothing creation; does not require skills in software development. Data can be exported and imported between MD and other common 3D tools.

Cost

30 day free trial. Monthly and yearly subscription licenses available, one-time fee USD 550.

SUBSTANCE PAINTER

https://www.allegorithmic.com/products/substance-painter

Texturing software with support for physically based rendering pipelines common in current game engines like Unity and Unreal. As a plus the model can be updated after texturing and the software reprojects textures to the updated model. Has baking functionality for creating different maps for masking and texturing purposes. Can export and package the created textures for many different game engines and renderers.

Cost

Depends of license: free 30-day trial, indie license $149 (under $100K revenue), pro license $590 ($100K-$100M revenue).

SUBSTANCE DESIGNER

https://www.allegorithmic.com/products/substance-designer

Node-based texture creation software with support for physically based rendering pipelines. Technically oriented, but allows creation of procedural tiling textures which can be used straight-away in supported game engines (e.g. Unity) and in Substance Painter to generate traditional texture sets. Textures created in Substance Designer format can have variables exposed by the texture artist. This allows quick changes of texture look in game engine, like color and smoothness or more complex variables like wetness and weathering.

Cost

Depends of license: free 30-day trial, indie license $149 (under $100K revenue), pro license $590 ($100K-$100M revenue).

AGISOFT PHOTOSCAN

http://www.agisoft.com/

A photogrammetry tool for creating 3D models and point clouds from photographs taken of a target from different angles. Supports as well small objects as entire environments. Standard and professional version with different capability profiles. The standard version suits AR productions well while the Professional license is targeted for high quality aerial imaging and manipulating pointclouds of very large environments.

Cost

Professional and standard versions have very different pricing. Educational licenses available.

MIRACLE OPEN SOURCE COMPONENTS

https://github.com/ututrc/

https://github.com/thomaspark/bootswatch/blob/gh-pages/LICENSE

A number of software components supporting implementation of MR applications was created in the MIRACLE project. The main components are described below.

All these components are published as open source, under the MIT license.

Cost
Free and open source.

MuseumExplorer Content Management System
MeteorJS based web content management system (CMS) to create and upkeep data for augmented reality applications targeted to cultural heritage sector. The system provides technical developers, content experts and eventually even casual users interfaces to access and modify the recorded data via interfaces targeted for each target group. The system employs a ARML 2.0 like XML data format to exchange data back and forth with client applications. Additionally, the system provides a 3D editor for use in web browsers to create and edit MR content.

MuseumExplorer Unity SDK
Unity based software development kit built with C# to create immersive augmented reality applications in connection with the MuseumExplorer CMS. The SDK provides all basic logic and functionality building blocks and allows any 3rd party tracker to be connected to provide the tracking data.

UX Lab
Meteor based data logging web service targeted for collecting user experience measurement data. Models data into user definable streams that can be used to feed in data via simple REST API. Provides rudimentary web UI to define the data streams as well as view and export the collected data.

GLOSSARY

360 video/photo
A video or still image the view of which covers the full sphere seen from the location of the camera that recorded the image.

AR
Augmented Reality

ARML
Augmented Reality Markup Language

Augmented Reality
The real world view is augmented with additional, artificially generated information, for example computer-generated 2D and 3D images that are superimposed on the real world view.

HMD
Head-Mounted Display. VR glasses like Oculus Rift and HTC Vive are examples of HMDs.

HUD
Head-Up Display. A transparent display that presents data without requiring users to look away from the usual field of view, typically using a reflecting glass that combines a monitor's image to the view that is seen behind the glass.

Marker (fiducial marker)
An object placed in the field of view, for use as a point of reference for positioning and tracking of an AR device. Figures consisting of black and white rectangular elements are typical AR markers.

Mixed Reality
An environment consisting of real and virtual elements. According to a classic definition, the term mixed reality covers everything that falls between reality (no virtual elements) and virtual reality (completely virtual environment).

Mocap
Motion capture. Recording the movement of objects or people. Motion capture can be used to animate 3D characters e.g. in animated movies or augmented reality applications.

MR
Mixed Reality

Optical see-through display
Eyeglasses with transparent display so that the user can see the actual environment through the glasses while virtual content can be added to the view by a display element. (see Video see-through display)

Photogrammetry

A process of making measurements from photographs, especially for recovering the exact positions of surface points. 3D models of objects can be made using photogrammetric methods on a large number of photographs taken of the object from different angles.

Point cloud

A set of data points in a coordinate system. In AR, point clouds can be used as tracking targets to define the device's location and orientation.

SDK

Software Development Kit

SLAM

Simultaneous Localization and Mapping. An augmented reality tracking principle, where the device creates and updates a model of the environment while the application runs.

Tracking

Keeping the exact location and orientation of an augmented reality display device updated during its use.

UV

UV coordinates are 2D coordinates used to define texture mapping for 3D objects. Called UV because XY were already taken. UV-unwrapping is the process of projecting a 3D object on a 2D plane.

Vertex

A single point in a coordinate system. 3D models are made of nets of vertices connected by surfaces.

Video see-through display

Head-mounted display where the actual environment is recorded via a video camera, virtual content may be added to the camera view, and the user sees the resulting video on the display.

Virtual Reality

An artificial environment generated by a computer and displayed to the user via displays, speakers and possibly other perception-generating devices.

VR

Virtual Reality