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# An Interactive Visualization of the Past using a Situated Simulation Approach

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**Abstract**—This paper describes aspects of the development of an interactive installation for visualizing a 3D reconstruction of a historical church chapel in Kolding, Denmark. We focus on three aspects inherent to a mobile Augmented Reality development context; 1) A procedure for combating gyroscope drift on handheld devices, 2) achieving realistic lighting computation on a mobile platform at interactive frame-rates and 3) an approach to re-location within this applications situated location without position tracking. We present a solution to each of these three aspects. The development is targeted a specific application, but the presented solutions should be relevant to researchers and developers facing similar issues in other contexts. We furthermore present initial findings from everyday usage by visitors at the museum, and explore how these findings can be useful in connection with novel technology for facilitating information transfer to a museum audience. The installation is in active commercial use and is currently logging further user interactions via in-application logging for future investigations in line with this project.

## I. INTRODUCTION

Museums provide a great opportunity for introducing new technology to a user-base in a semi-controlled environment, in order to investigate user behavior and user acceptance out of the lab and in a contextual setting. The setting for this project is Koldinghus Museum, a historical castle dating back to the mid 1200s, placed in Kolding, Denmark. In 1808 the castle burned to the ground, leaving only the bare walls standing. The castle was restored to a museum in the 1970s.

This project is part of a currently ongoing series of Cultural Heritage (CH) projects in collaboration with Koldinghus Museum, aiming at creating new technology driven installations for the museum to facilitate information and learning of the history at the museum in a novel way. The aim of this project has been to conceive a visualization of the chapel as it appeared when built, using off-the-shelf hard- and software. The installation has to operate robustly 10 hours a day, 7 days a week in a room with no staff. This meant, that in addition to an interactive visualization running in real-time and facilitating information transfer to guests, there was an added constraint of an autonomous installation which requires no supervision. Furthermore, the location of the installation has multiple purposes, which means the installation must be easily transportable to other locations within the chapel.

The purpose of the installation is to deliver an interactive visualization of Koldinghus Chapel as it appeared in 1604 after a large renovation. This has been facilitated through Augmented Reality (AR) technology, to display the visualization of



Fig. 1. Usage of the installation on the launch day. A child experiences the systems 3 degrees of orientation freedom of the visualization.

the past chapel room through a window (tablet) into the past, placed at the physical correct location in the present setting.

Visitors enter the chapel which is a 10 by 20 meter open space. Along the wall is a podium with docking stations holding two iPads, each running the application. As depicted in Figure 1, users can grab an iPad, hold it and use as a viewfinder exploring the space. Interface options are given on the iPad, allowing the user via touch to translate the viewfinder position to predefined positions in the chapel. The user should then position himself accordingly in the physical world to achieve a coherent experience of the two spaces.

This contribution describes an approach for the development of the interactive installation using AR technology. We focus on three aspects that were considered crucial for development of the project; 1) A procedure for combating gyroscope drift, 2) achieving realistic lighting computation on a mobile platform at interactive frame-rates and 3) an approach to re-location within this applications situated location without position tracking. We focus this paper on development challenges that are inherent to a mobile AR development context.

The paper is organized as follows: In Section II the work presented in this paper is positioned in relation to previous work. Section III gives an overview and summary of the location and setting. Section IV describes the system, in which the three crucial aspects for development is explained in detail. Section V presents an initial evaluation of the system on visitors at the museum, based on user data autonomously collected on the device, before summing up with conclusions, and directions for future work in Sections VI and VII.

The installation has been actively running in multiple iterations since November 11<sup>th</sup> 2012, and in its current iteration since April 24<sup>th</sup> 2013, which is the version described in this paper. During this time the application has logged usage data to assist in uncovering usage patterns.

## II. RELATED WORKS

There is a vast body of work within the field of AR in museum contexts, ranging from museum guides [1], [2], [3], to building virtual and augmented installations and exhibitions for the museum [4], [5], [6], [7], [8], [9]. Novel technology in museums is an active and vast research area from both a technology point of view, to test new technology in a semi-controlled setting, but also from a CH point of view; considering how to best present information and knowledge to a user. Van Eck [8] considers how to augment paintings in the Van Gogh museum and describes the different information overlays, while [6], [7] presents research on information presentation in a way which are normally not readily available to users, such as the universe (S.O.L.A.R. System) and the Interactive Antarctica.

Within CH, there is a lot of work being done with Virtual Reality [10], ranging from specialized work within 3D model reconstruction to user interaction and acceptance evaluations. Guidi [11] describes two approaches to 3D modelling in CH. One is the representation of the moment "as is" through different approaches and technology, and the other is the previous hypothetical state through a scientific reconstruction process, and presents two examples of work in relation to this. Kersten [12] presents work on modelling a city based on a 3D scanning approach. Trapp [13] describes how the user is now able to explore CH artifacts in real-time, and presents the technical concept for implementing this. Another example is work done by Zöllner et al. [14] for a museum setting allowing in one case a single degree of freedom for interaction by horizontal rotation of an installation stand (MovableScreen) and in another case a handheld device (UMPC) with other affordances. The aim here was to present information from remote CH sites at museums. Another example of work close to the described application in this paper is TimeScope 1 for Enne 974 [15], a church visualization for an archaeological park as a static installation with no interaction aspect, aiming at presenting an early medieval abbey on video shot of the foundation.

It is discussable whether the work presented in this paper falls under the umbrella "Virtual Reality" or "Augmented Reality". One could argue that the entire visualization is, in terms of technology, not connected to the real world, and thus is a virtual reality enabling technology. Another argument is that since it is in fact linked to the geo-physical setting, it becomes an augmentation of the setting, thus it is an AR technology in this setting, and this setting only. This point of view has been discussed also by Liestøl et al. [16], who stress that according to Azuma's discussion on AR it is explicit that the term should be general and not based on technology [17], [18]. Thus, it can be inferred, that instead of merging real and virtual realities on the device, the users mentally connect the geo-physical setting and the virtual presentation, based on real and virtual landmarks in combination. This discussion will be

elaborated further in further in Section VI for further research within this area.

Liestøl et al. defines this augmentation in a defined setting as Situated Simulations, here defined as a virtual reality enabling technology for augmenting the geo-physical correct setting where it belongs [19], [20], [16].

The ideas of visualization and presentation of information on site is closely related to the work presented in this paper. We aim to further expand the freedom of exploration to allow for 3DOF orientation by hardware sensors in the system, and allowing for semi-freedom in translation by facilitating translation changes in the application, and let the user adapt to the virtual position in the geo-physical space. This builds on the previous work, which presents and adds more freedom in the user exploration.

While the presented work all evaluate their efforts in AR as being generally accepted by users and present findings that users are very interested in this novel technology, it can be speculated whether this is a "wow" effect of novel technology, or whether the effect will last. We consider it relevant to look into the realism of the presented objects, to create a closer connection to the physical world. In order to achieve added realism in the virtual representation of the chapel, we consider how to use pre-rendered and on-device rendering of illumination information to achieve a high degree of realism in the final visualization which is robust for position changes in the physical surroundings.

We also describe in this paper some of the aspects needing considerations for most AR development projects, which has not been discussed in the related works, such as combating gyroscope drift and achieving translation changes in a novel manner. We also enter the area of visual realism in the visualization and considers how to facilitate this at interactive frame-rates on a mobile device. Lastly we discuss methodology for usage of an application in a geo-physical correct environment to investigate how the user experiences the link between the real and virtual worlds when the link is not on the device itself.

## III. LOCATION OVERVIEW

The Koldinghus castle dates back to the mid 1200s, and has through history been a place for both protection of the Danish borders, residency for kings and the royal family, and has played a central role in the history of Denmark.

The construction of the current chapel and tower of Koldinghus was started in 1597 due to a fire in that part of the building. The simple chapel of the time was not as grandiose as envisioned a church chapel should be, according to the king. He wanted a new and bigger church, which was to be the base for the tower to be built. This new chapel was to be a reflection of the king as God's representative in both ecclesiastical and secular affairs. The new chapel was finished in 1604. [21]

During the Napoleon wars in 1808 the castle burned to the ground due to a fire started from a chimney in the guardroom. This fire destroyed the castle completely over a period of two days. However, the chapel and tower are not restored until the 1970s. The chapel was restored to a bare minimum with little alterations made to the standing ruin. The bare walls are displayed, and the chapel received a new floor and ceiling. The



Fig. 2. Overview of the physical castle chapel (left) and the 3D visualization as represented in the installation (right).

present chapel can be seen in Figure 2 in combination with our rendered visualization.

#### IV. SYSTEM DESCRIPTION

In order to develop a usable product for both the visitors and the museum staff, some requirements are considered for the design of the system. These are listed in Table I. First, as the task of the system is to facilitate information to the guests, who can range from families with children to elderly couples, the system in itself should be self-explanatory and easy to use for the average unskilled visitor with limited experience in technology. The system should be robust enough that it will not end up behaving in a way that the user does not expect, and thus ending up confusing or frustrating the user. Second, the museum personnel require a system with low cost and low daily maintenance as well as a highly transportable system. The chapel area, which the system will augment, is regularly a forum for exhibitions and events that require the floor space of the chapel. In these events, the system might need to be set aside for a small period of time, such as an evening or for a couple days, and then brought in again.

Apart from the user and staff requirements, Table I also describes technical requirements to be met for a successful and functional product. The system itself should be able to process the visualization of the chapel ruin at interactive frame-rates, and be able to run during opening hours without being charged. The processing power of the system should be sufficient to handle these requests while the requirements of the visualization. The polygon count and the shader performance should be optimized to fulfill these requests.

The following sections will elaborate on some of the problems encountered during the development and how to overcome these problems in the areas within hardware, software, reconstruction and realistic daylight simulation.

##### A. Hardware

Using the gyroscope as the only sensor for estimating orientation is not feasible due to accumulated drift over time. Figure 3 illustrates an early test of the gyroscope drift measurement over the course of one full day. It revealed more than  $10^\circ$  drift over a period of 28 hours. As the application is required to function unsupervised for a full day, this amount

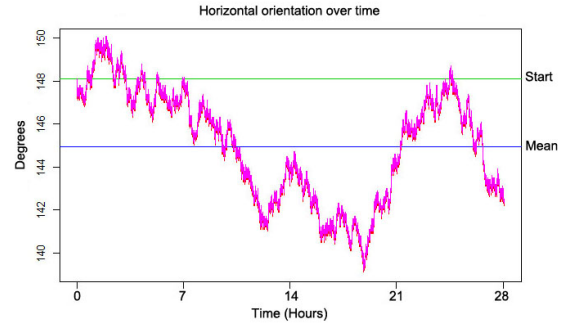


Fig. 3. Horizontal drift of the gyroscope over the course of 29 hours in a static placement.



Fig. 4. A version of the handheld installation, as it was displayed during testing in the Koldinghus Chapel.

of drifting over time suggests that additional information of the orientation is required.

Initial considerations for the hardware were to use a combination of internal compass and gyroscope sensors in combination to estimate rotation and set calibration offset from north, both to combat drift from the gyroscope over time, but also to calibrate the orientation to the geo-physical room itself. However, experiments with the iPad showed that the compass was far too inaccurate to provide any decent magnetic orientation estimation for the chapel setting. A lab experiment was conducted, emulating the conditions of the chapel (electronic devices nearby, indoor) with exception of the granite structure of the chapel. The measurements gained from the iPad compass varied from  $-14^\circ$  to  $+56^\circ$  from north. With these inaccuracies of the compass for this particular setting, we opted to find a novel solution to calibrate the iPad to the chapel setting and limit the drift from the gyroscope over time and not rely on the compass in addition to the gyroscope.

This solution was implemented in the next iteration of the prototype. As a substitute for the compass, the docking station was used to calibrate the iPad to the orientation in the geo-physical world (Figure 4). The use-case dictates that the



TABLE I. OVERVIEW OF SYSTEM REQUIREMENTS

| Museum guests               | Museum personnel      | Technical                       |
|-----------------------------|-----------------------|---------------------------------|
| Light weight                | Flexible placement    | Low power consumption           |
| Easy to handle              | Low daily maintenance | Long running time               |
| Visualization true to world | Easy to setup and use | High frame-rate                 |
| Self-explanatory            | Low cost              | Limited polygon count           |
|                             |                       | 3DOF orientation                |
|                             |                       | Translation of user perspective |
|                             |                       | Robust                          |

application, and the iPad, can be in two different modes of operation: 1) the iPad is in the docking station, is totally static and charging, and 2) the iPad is held in the hands of a visitor and will move around for some length of time. As software detection of the charging state is simple, the static docking state is easy to detect in the application. The application behaviour in the two states is thus:

**Charging:**

Reset model orientation to the calibrated orientation

**Not charging:**

Rely on gyroscope readings to track the orientation

An added benefit to using the docking station is the ability to estimate the total number of uses by assuming that each usage is occurring when one user takes an iPad from the charging station (start) until it is returned to the charging station (end). It furthermore allows us to only log interaction data during this time period.

In the final version of the installation, currently at display and in active use on location, the application is able to function autonomously for an entire day after being setup by the museum staff. This setup and calibration procedure has three steps: 1) Start the application if it is not already running (most of the time it will be running continuously for days). 2) In handheld mode, touch-drag on the screen to calibrate the horizontal orientation by orienting the visualization to the desired orientation to match the physical space. 3) Disable the touch-dragging via a hidden in-application menu. Following this, the iPad will work autonomously during the day, and should there be any problem due to drift, the museum staff can repeat the procedure again, or restart the application to reset everything, if desired.

### B. Software

The museum, and we, wanted to provide users with the freedom to walk around and explore the chapel. This of course requires position tracking, which we deemed technically and economically unrealistic. The compromise was to re-locate the viewpoint to predefined circles marked on the floor in the visualization, allowing the users to move and experience the model from multiple locations.

To handle in-application translation changes we implemented a method for jumping between pre-defined locations in the virtual chapel via the user interface. These predefined locations are depicted in Figure 5. The user must place himself accordingly in the geo-physical world to experience the link between the real and virtual environment. With this interaction

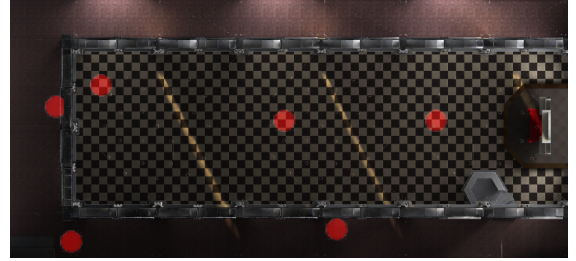


Fig. 5. Depiction of the floor plan of the chapel, with red marking visualizing areas the user can translate to and experience the visualization from.

method, the user is able to experience the chapel from multiple locations using a low-tech translation approach.

For this project, we develop the software using the Unity game engine<sup>1</sup>, allowing for efficient development for multiple platforms: iPad tablets initially, with option to easily deploy to other platforms later.

In order to process the visualization on the iPad at interactive frame-rates, we had to set strict limits on polygon-count for the visualization, limit the amount of draw calls and static objects to be rendered for each frame, and pre-compute most of the lighting information to light maps split into direct and indirect lighting. The latter will be elaborated later in the paper, when discussing the shading of the model. To a large extend objects should be combined to reduce individual calls to draw objects. As Unity supports a maximum texture size of 2048x2048 for mobile devices, this set a natural restriction in the size of objects, without having to use multiple texture maps per object. In a trade-off between detail and real-time visualization of the model, the polygon count for the model was reduced to an acceptable level, which allowed for a high amount of details from the possible viewport position. This estimate was determined subjectively by the developers on a per-object basis. The overall polygon count for everything in the viewport never exceeds 150.000 polygons at any one time for any position and view direction on this hardware<sup>2</sup>.

### C. 3D model generation

For the 3D visualization of the chapel, information was collected in three ways. 1) research in literature, 2) scanning and modelling from artifacts available at Koldinghus and 3) informed guesses to fill in the gaps.

<sup>1</sup><http://www.unity3d.com/>

<sup>2</sup>We used Apple's 3rd generation iPad featuring an Apple A5X chip (Dual-core 1 GHz Cortex-A9 processor with a PowerVR SGX543MP4 GPU), and a 2048x1536 (264 ppi) resolution display

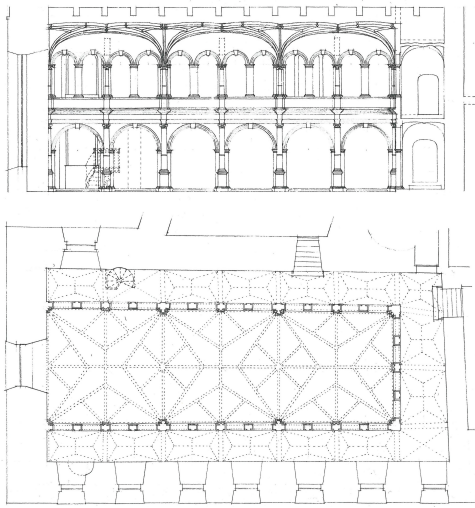


Fig. 6. Example scanning of illustrative literature on Koldinghus Chapel interior. Here top and side view of the chapel.

For the first part, research in literature, information was collected from available books about the chapel, informational posters and paintings in general from the castle which could aid in the generation of the virtual model (Figure 6). There are no paintings or detailed informational drawings of the chapel from prior to the castle burning. The majority of the information available on the castle and the chapel is from research and reconstruction drawings.

Secondly, the scanning and modelling process was separated in three parts, 1) the core dimensions of the chapel and window placements were acquired by laser distance meter, and the room manually modelled in these dimensions in Maya<sup>3</sup>, 2) details manually modelled from existing historical sources and drawings, and 3) whenever possible, details of stone ornaments were used by 3D reconstruction from images (Figure 7) using 123D Catch<sup>4</sup> from Autodesk.

Third, as there unfortunately are no paintings or detailed drawings of the chapel from the period before the castle burned, a lot of information has been lost. In order to compensate for this lost information, in the visualization we have filled in the gaps of missing information with "best guesses" of how it probably might have appeared in 1604. History informs us that there are more useful data than what is present at Koldinghus. Frederiksborg Castle Chapel was built shortly after Koldinghus Chapel, ordered by the same king. In an attempt to further expand the knowledge of the interior of Koldinghus Chapel at the time, Frederiksborg Chapel was used as inspiration to the generation of the virtual model for areas in which there were limited or no information available of the true decor at Koldinghus Chapel. Additionally, the alter placed at Vor Frue church in Aalborg, was sculpted by the same sculptor as the original alter in Koldinghus. This alter at Vor Frue church was destroyed in a fire in 1902. There exists pictures of this alter from that time, which was heavily used as inspiration for the visualization of the Koldinghus Chapel alter.

<sup>3</sup><http://www.autodesk.com/products/autodesk-maya/overview>

<sup>4</sup><http://www.123dapp.com/catch>

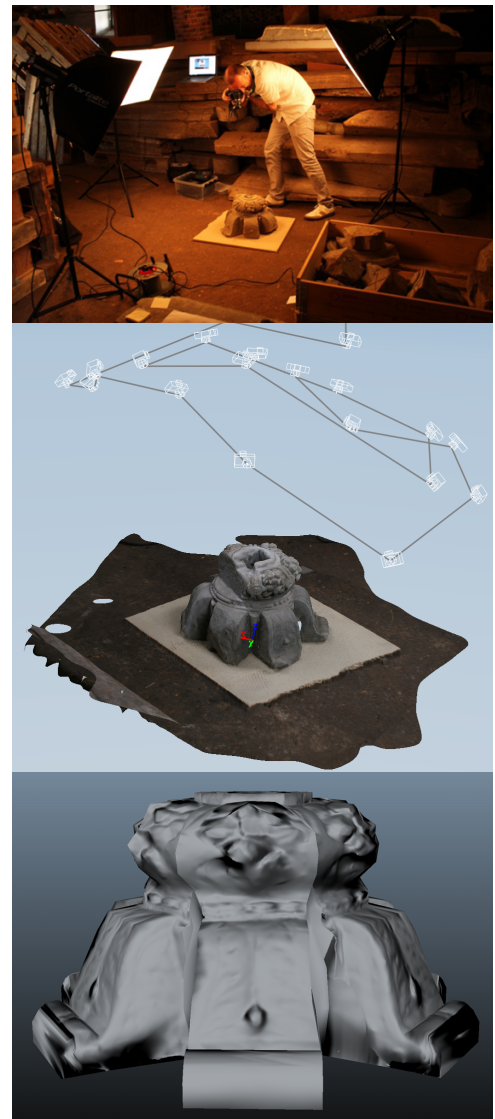


Fig. 7. Process of generating the virtual content from image capture using 123D Catch software. The generated high-res model is then manually remodelled into a low-res object plus a texture and normal map.

The final visualized model is a results of a compromise between what is factually known about Koldinghus Chapel prior to the fire in 1808 and what is by experts considered to be a very plausible appearance considering what was ordered built by the king in other areas of the country during the same period as building the chapel at Koldinghus. It is presented to the visitors as this compromise, with a supporting physical note stating that this is a "best guess" representation of the chapel. Giving visitors the option to choose between "known" and "best guess" options in the application is considered a future implementation.

#### D. Shading

As stated above much energy was put into creating a realistic 3D model of the chapel, but all this effort is in vain if the model is not rendered with a high degree of realism. An essential part of the aesthetics of architectural visualization is in how the light travels through the space.

In a case such as this, the illumination is fundamental in creating the right atmosphere, i.e., a lush renaissance chapel. In Figure 8 we illustrate how our illumination rendering adds in creating the right atmosphere for the chapel. Obviously, real-time full global illumination rendering is not computationally realistic, especially on a mobile device. Luckily, there are some constraints that can be utilized: 1) the scene is static, and 2) the museum is satisfied with a visualization based on a fixed time of day, i.e., the direction vector to the Sun can be treated as a constant. With these two constraints/assumptions it would be natural to opt to pre-compute the entire illumination. Nevertheless, since the user can re-locate the viewpoint to various locations within the chapel, the viewpoint-dependent effects (specular reflection) must be rendered at run-time. We therefore propose to pre-compute all view-independent lighting effects, and only render specular reflection in real-time.

A formal description of our approach to achieving this takes a starting point in the rendering equation, [22], describing the reflected radiance,  $L(x, \vec{\omega}_o)$ , at a point  $x$  in the scene in a certain observation direction,  $\vec{\omega}_o$ :

$$L(x, \vec{\omega}_o) = \int_{\Omega} f_r(x, \vec{\omega}_i, \vec{\omega}_o) L_i(x, \vec{\omega}_i) (\vec{\omega}_i \cdot \vec{n}(x)) d\vec{\omega}_i \quad (1)$$

Where  $\Omega$  is the hemisphere defined by the surface normal at the location,  $f_r$  is the Bidirectional Reflectance Distribution Function (BRDF), and  $L_i$  is the radiance from an incidence direction given by  $\vec{\omega}_i$ .

We pre-compute the direct and the indirect illumination parts of the view-independent illumination in Maya and store it in separate light maps, for reasons that will be explained shortly. The light maps are rendered with a standard daylight model, and the chosen date and time is November 3rd, 2012 at 14:00. This choice gave an aesthetically pleasing fall of light through the main windows in the wall facing West. Given the pre-computed light maps the rendering equation can be re-written as:

$$L(x, \vec{\omega}_o) = \frac{\rho(x)}{\pi} (LM_i(x) + LM_d(x)) + k_s(x) L_s(x) (\vec{\omega}_o \cdot \vec{R}_s)^\alpha \quad (2)$$

Where  $LM_i(x)$  and  $LM_d(x)$  are the indirect and the direct illumination light maps, respectively, which in radiometric terms store irradiance information. The diffuse part of the BRDF is represented with the albedo,  $\rho(x)/\pi$ . The specular reflection is simplified as there is only one light source, namely the Sun. The specular reflection is modeled from the Phong reflection model with a specular reflection coefficient,  $k_s$ , the radiance of the Sun,  $L_s$ , a geometry term with the dot product of the observer direction and the reflection direction for the Sun,  $R_s$ . Given the almost infinite distance to the Sun this direction is not position dependent.

The specular contribution in eq. 2 is computed in real-time in a fragment shader (Figure 9 is an example of this). The specular reflection coefficient is manually tuned to get a desired glossy appearance of especially the floor tiles. The position (fragment) dependent incident sun radiance,  $L_s$ , is

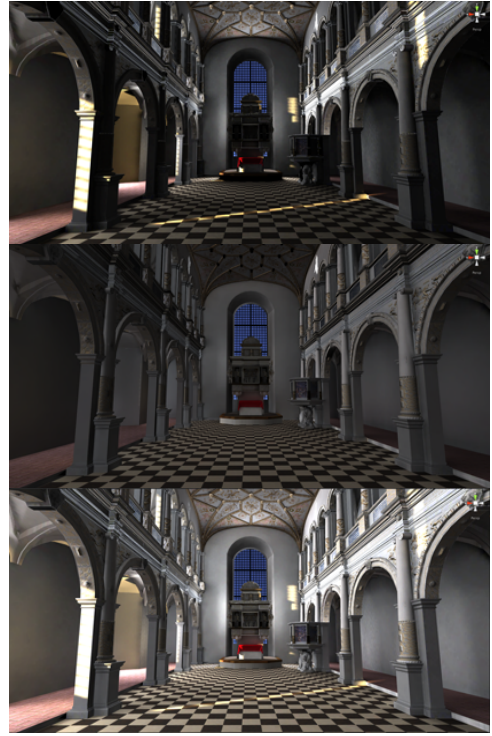


Fig. 8. Direct lighting, indirect lighting, and a combination of direct and indirect light in an example scene of the visualization of the chapel.

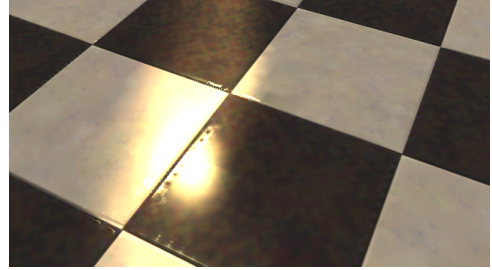


Fig. 9. Example of real-time computed specular reflections in the visualization.

also manually tuned, but the real challenge is that obviously in most positions inside the chapel, the Sun is not directly visible, i.e., many points are not illuminated directly by the Sun. We handle this in the shader implementation by thresholding the value read from the fragment's direct light map (hence the need for having separate direct and indirect maps). If the values are above a certain low threshold, the fragment is in direct light and the specular contribution is computed. If below the threshold, no specular contribution is added. In the shader the albedo is read from the texture map. Normal maps are used in conjunction with the geometry when rendering the light maps, but not in the shader, as the normal information is already taken into account in the light maps.

## V. EVALUATION

Usage data of the application has been logged on the deployed devices during the period from March 3rd to April 24th. The purpose of the logged data is to investigate which areas within the chapel are of interest to the users. This allows



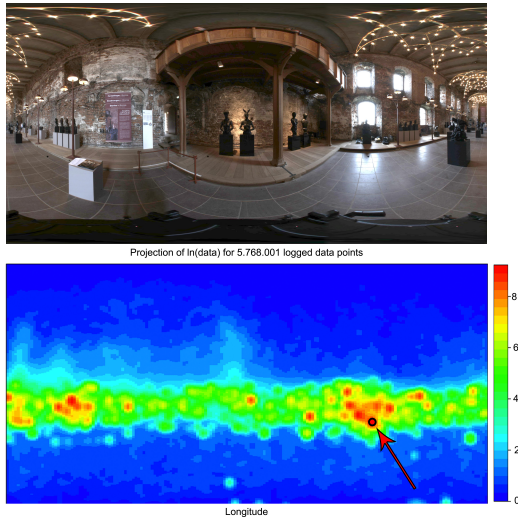


Fig. 10. The virtual model of the chapel at Koldinghus expressed in longitude-latitude format (top). The sculptures depicted were part of a temporary exhibitions, and not permanently in the chapel. Additional orientation data logged from one specific logged location, plotted on a correlating map (bottom). The red dot illustrates the location of the charging station.

for further development of the application, with focus on which areas should be augmented with additional information of relevance to chapel, in order to inform or inspire visitors to learn historical facts from the chapel.

Orientation data from the iPad has been logged with a resolution of  $0.1^\circ$  at 0.5 second intervals, throughout the day. This gives us an idea of the areas of interest with sufficiently high accuracy. Figure 10 shows a long-lat map of the visualization of the iPads as well as a plotting of the iPad orientation in relation to the virtual model from a specific position in the virtual space. It is relevant to consider to what extend the users' interest in specific areas is representative for what they are experiencing in the virtual space, or do they aim to connect it to the physical space. The data presented in the figure is only of value if we can assume the users are positioned physically within a small radius of the virtual position in the chapel. This question is a case for further studies following this project.

The degree of exploration of the virtual space is an interesting observation from the data, for one (or more) of three possible reasons:

- 1) It would appear that visitors either are satisfied with the interaction and information from the horizontal plane, or that they simple do not give much attention to the ceiling and floor.
- 2) Perhaps vertical motions with handheld devices are unfamiliar for most visitors, making it seem out of place for people to doing so in a public space.
- 3) Maybe the visitors are simply not curious for exploring the area.

An observation mentioned by the staff at Koldinghus, is that they noticed visitors appearing to be very interested in the application, but did not interact with or touch the tablet, which in stationary mode is displaying a bare wall. Next to the stand there is a clear short written guide stating the purpose of the

installation which makes it clear that the main purpose of the installation is for the device to be actively used. We can only speculate the reasons for this. One argument is that visitors are used to artifacts on a museum is to be seen and not touched, and thus they, based on prior experience, observe objects from this mental notion, either in a conscious or subconscious way. Another argument is that these visitors simply focus on the installation and are not paying attention to any writings near the installation. This could be interesting to consider for further investigations in facilitating information using AR technology.

## VI. FURTHER STUDIES

In the current version of the application, the user has the ability to move around between 6 different locations in the chapel and have the application follow along to this position. This gives the user options for a more wide and free use of the application and allow for the possibility to come in close to objects of interest, or to inspect the chapel from the gallery at the first floor balcony. Both the virtual position and orientation are being logged continuously, in an attempt to uncover in more detail what visitors areas are interested in. In a future study, this data is coupled with user data from staff and visitors, to investigate to what degree the visitor link the virtual and physical world using a mental connection. One outcome of such a study is to give an idea what the situated simulation adds to the experience, or whether the experience would have sufficed with the same application in another setting, not linked to the visualization? And is a Situated Simulation part of AR if this is the case?

In mixed reality settings, it is unclear to what extend users are interested in experiencing the world, and how the curiosity of the user can be stimulated to further explore an area in a mixed reality setting. In order to test user exploration in virtual scenes, Madsen and Lorentzen investigated the use of visual augmentations to influence user movement within a small region of exploration [23]. User exploration was also one defining factor from Madsen et al. [24] in lessons learned from a previous project in collaboration with Koldinghus Museum to facilitate knowledge transfer through novel technology. The considerations for user exploration is interesting as this is a hard subject to gather information on. To the best of the authors' knowledge, this is an unexplored research area, however relevant for the user acceptance of the enabling technology. This work could bring attention to areas of the visualization that could benefit from additional information by adding active data, text or images as part of the application to convey information to the visitor.

Future work in the area of rendering for this application includes relieving the constraint of a fixed time and date for the Sun position. We are currently further developing techniques presented in [25], enabling us to render the chapel at any time of day, such that the user gets to experience how the illumination of the chapel changes over the course of a day. Exploring the increased visual realism and how users perceive this in a CH context is another interesting continuance to this line of development.

## VII. CONCLUSION

In this article, we have described the implementation process of a novel application leveraging on AR technology.



The implementation process has been described in detail from gathering of relevant information to the construction of the virtual model in 3D.

The contributions of this paper are in detailing the visualization process of the castle chapel in the following areas: 1) 3D reconstruction from images is a mature technology, being used in this project to enable highly detailed models of objects, 2) a novel approach to combat drift in mobile applications relying on available hardware, 3) an approach to realistic rendering of global illumination for a single point in time on a mobile device, while maintaining freedom in translation and orientation.

A preliminary investigation of the application usage has been completed with interesting results of the users interest area within the frame of this situated simulation. It appears that visitors are mostly interested in looking at the virtual scene horizontally despite efforts to create a full implementation of the chapel itself. The findings point out a couple of obvious considerations and opportunities for further studies in the area of user exploration of virtual scenes, such as how to design an interaction model to direct the users focus to specific interesting artifacts or other points of interest.

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