# Final Report

Leibniz Transfer

# Digital Materialities. Virtual and Analog Forms of Exhibiting Museum Artifacts

# (DigiMat)

**Application Number:** T91/2020

**Lead Institute:**

German Maritime Museum – Leibniz Institute for Maritime History (DSM), Bremerhaven

**Applicants:**

Prof. Dr. Ruth Schilling (DSM)
Prof. Dr. Lucio Colombi Ciacchi (MAPEX)
Prof. Dr. Stephan Schwan (IWM)

## Executive Summary

A brief overview of the key aspects of the 2023 calendar year interim report, submitted in spring 2024, is provided here. At the time of the previous report, despite temporary travel restrictions due to the pandemic, the project remained largely on schedule in achieving its major milestones, including the use of allocated funds. By the time of the 2023 annual report, the special exhibition "X-ray. The Ocean" had already opened. Numerous lectures, guided tours, and science communication events have been linked to this exhibition. However, the evaluation of visitor surveys, aiming at the assessment of shared potential of physical and digital objects and conducted in autumn, winter, and spring 2023/2024 within the exhibition space was still pending. The analysis and results of these surveys, which formed the primary basis for the cost-neutral extension request for an additional five months (until August 2024), are presented in this report.

## 1. Achievement of objectives and milestones

Within the Digital Materialities (DigiMat) transfer project the MAPEX Center for Materials and Processes at the University of Bremen, the Leibniz-Institut für Wissensmedien (IWM), and the German Maritime Museum (DSM) digitized and analysed museum collection objects of various materialities using materials science methods. Examination of these objects occurred from a technological and cultural studies perspective and explored the learning psychology potential of integration of the physical objects with their virtual representations in museum exhibitions. The project partners aimed to establish long-term infrastructural and procedural conditions for the digitization and materials science analysis of selected museum objects and collections. All milestones and objectives outlined in the project proposal have been achieved, albeit with a five-month delay due to the pandemic until August 2024.

The project’s work packages "Digital Imaging Using Materials Science Methods" (WP1), "Observer-Object Interaction" (WP2), "Travelling Display" (WP3), and "Data Storage, Retrieval, and Web Interface" (WP4) were interdependent, with the latter building upon the materials science scan data collected and the exhibition developed by the project partners.

## 2. Activities and obstacles

At the time of the initial project proposal, it was not foreseeable that pandemic-related travel restrictions would make in-person meetings difficult. As a result, project meetings were conducted primarily in virtual formats. Given the diverse academic disciplines involved, this virtual format required more time for certain work steps and discussions than in-person meetings would have.

### 2.1 Digital Imaging and Processing Using Materials Science Methods

The team led by Prof. Dr. Lucio Colombi Ciacchi (Hybrid Materials Interfaces Group, University of Bremen) conducted various X-ray scanning procedures on DSM collection objects as a preparatory step for visitor studies and museum transfer formats.

The primary method used for digitizing museum objects was X-ray microtomography (µ-CT) **(Fig. 1)**. The captured two-dimensional scan data were reconstructed into 3D image datasets, forming the foundation for all subsequent digital image processing of the microtomography images. As an additional step, 3D surface models of the objects (or multiple partial models, if needed) were generated from these reconstructions.

The digital analysis of the associated finds from the late medieval merchant ship "Bremer Kogge" has e.g. provided new archaeozoological and archaeobotanical insights into caulking materials and rigging. Additionally, knowledge about the manufacturing quality of the recovered ceramics, including Siegburg stoneware, has been refined. Similar new insights

were gained by project partners in the analysis of organic materials, many of which could now be more precisely assigned to specific material groups and animal species than before.

### 2.2. Special Exhibition “X-ray. The Ocean”

From October 19, 2023, to November 3, 2024, the German Maritime Museum hosted the special exhibition "X-ray. The Ocean", showcasing physical museum objects alongside their digitally created counterparts. This exhibition provided new insights into navigation, seamanship, maritime medicine, and many other aspects of seafaring and its material culture (**Figs. 2-5**).

The physical objects were displayed in showcases placed around the exhibition space, while the digital objects were presented inside a darkened chamber. Using the Pepper’s Ghost illusion technique, a combination of a screen and an angled mirror projected the digital models into the space as seemingly floating holograms. Visitors could access additional research findings on a media station **(Fig. 6)**, linking the physical and digital exhibits. After the exhibition's run at the German Maritime Museum, key elements of "X-ray" were integrated into the annual exhibition "Von der Idee zum Ergebnis" at the Haus der Wissenschaft, Bremen, from November 2024 to February 2025 (Exhibition Archive 2024).

The contents and structure of the "X-ray" exhibition were adapted into a permanent web-based version, programmed in Pageflow (Seh-Stücke Web Application). Similar to the physical exhibition, users of the web version can explore the three thematic groups on their private devices. Focus remains on the scientific insights gained through materials analysis, highlighted through graphics and informational texts. The didactic structure of the web version closely follows the media station from the on-site exhibition, ensuring a cohesive learning experience.

## 3. Results and successes

### 3.1 Visitor Research: Data Collection and Analysis

The subproject led by the IWM conducted five studies in Tübingen on the impact of the duality between X-ray-based digital exhibition objects and physical reference objects on visitor reception. A sixth IWM study focused on the joint special exhibition "X-ray. The Ocean" at the German Maritime Museum.

The first IWM study examined theoretical models of the interaction between object, medium, and visitor. This research question was explored in an experimental exhibition on "Whales and Humans" (02.11.2021-08.03.2022, see **Fig. 7**). Cognitive, emotional, motivational, and behavioural data were collected and compared among participants who visited the exhibition either with or without an interactive, zoomable digital model on a tablet. The results indicated that merely providing digital objects is not sufficient to significantly influence visitor reception in terms of cognition, emotions, motivation, and behaviour. Instead, didactic concepts are necessary to meaningfully integrate digital models of exhibition objects and relate them to their physical counterparts for significant impact.

The second study (25.11.2022-14.12.2022) integrated X-ray-based digital models of five different exhibition objects as videos with an interactive slider in the online exhibition. These videos displayed the X-rayed objects from all angles and inside, zooming in on two specific details mentioned in the accompanying object text. The videos were placed next to a photo of the original object, which only showed one of the two details visible in the digital X-ray models, adding an educational benefit. Participants visited the online exhibition either with or without the X-ray-based digital models. It had been hypothesized that these models would enhance visitors' focus on materiality, details, and open questions while stimulating spatial and cognitive multi-perspectivity. However, the results did not confirm these effects.

In the third study (24.01.2023-21.02.2023) participants also visited the online exhibition either with or without the X-ray-based digital models. The study hypothesized that these

models would improve interpretation skills for X-ray images, retention of details shown in both photos and digital models, as well as retention of details visible only in digital models. Furthermore, it was expected that these models would enhance retention and transfer of underlying principles – i.e., the significance of the shared detail in both the photo and the X-ray-based digital model for cog shipbuilding. The results did not confirm the assumed effects on various aspects of competence and knowledge acquisition.

While studies 1 to 3 examined digital replicas as supplements to their reference objects, the fourth study (04.10.2023-24.11.2023) focused on digital models as stand-alone objects. This study analysed reception and knowledge acquisition in an experimental exhibition on "Whales and Humans," featuring different content than the first study. The exhibition included three real objects and three holographic objects made visible using Augmented Reality (AR) technology via HoloLens 2 (**Fig. 8**). The results showed that while the quality of holographic objects was rated as moderate, they were nevertheless viewed longer and with more mental effort than real objects. Real objects, however, were perceived as more present, real, impressive, and authentic. No differences were found between object types in terms of their testimonial value for information in object texts, knowledge acquisition, or perceived contemporary relevance.

A fifth study, conducted as part of a bachelor's thesis at the University of Tübingen (02.04.2024-16.05.2024), examined the influence of digital replicas displayed via Pepper's Ghost technology versus a regular media station screen in an experimental exhibition (**Fig. 9**). The results showed no significant differences between the two display methods. However, participant comments suggested potential improvements to the media station, such as increased visual variability, interactivity, and visual cues highlighting aspects of the digital model mentioned in the audio text to guide visitor attention.

Concurrent with IWM's fifth Tübingen study, DSM and IWM conducted additional exploratory visitor surveys in the “X-ray” exhibition using the LimeSurvey software (24.11.2023-31.05.2024). The IWM used a questionnaire from studies 3, 4, and 5 to assess visitor perceptions of physical objects, digital objects, and object photos, while the DSM questionnaire focused on broader aspects of the analog-digital exhibition experience and perception and learning effects.

The 13-question DSM survey in the "X-ray" exhibition was answered by a total of 88 participants and data analysed by an external expert under a service contract. Among respondents, 57% were male, 35% female (**Fig. 10**). Only 2% reported living outside Germany, with 55.2% of domestic participants residing outside Lower Saxony and Bremen. Notably, 51.7% discovered "X-ray" by chance, while 30% attended based on personal recommendations, and 20.7% due to advertising. Only 9.6% visited due to interest in digitization, 13.3% due to interest in DSM research, and 38.6% for general maritime interest. Measurement and navigation instruments (56.8% and 53.4%) were the most engaging topics, followed by craftsmanship. Satisfaction was clearly higher for the physical exhibits (61.4%) than it was for the Pepper's Ghost holograms (39.8%). While most respondents were satisfied with station design, accessibility, themes, and text clarity, only 27% were "very satisfied" with information depth. Visitors requested additional details on object origins, function, and significance. Overall, 39.8% rated the exhibition as "very good" 35.2% "good" 13.6% "satisfactory" 1.1% "adequate" 2.3% "poor" and 1.1% "inadequate", while 6.8% gave no rating (**Fig. 11**). The 27-question IWM study in the DSM exhibition assessed perceived potentials of real objects, photos, and 3D digital models. Results showed real objects were valued for cognitive, emotional, motivational, and didactic reasons, while 3D digital models were appreciated for behavioural and collection-related processes. Photos were not rated highest for any potential. The findings emphasize that real objects remain essential, and digital 3D models should be interactive, multiperspective, scalable, and dynamic.

### 3.2 Presentations, publications, and science communication

A comprehensive overview of the presentations, academic publications, popular science publications, and science communication activities resulting from the project is presented in the tabular form. Some knowledge transfer formats (**Figs. 12-13**) continue beyond the project's duration (see e.g. below on ship's chronometer), demonstrating the long-term usability of the data collected.

## 4. Equal opportunities, career development and internationalisation

The measurement data obtained through X-ray microtomography has been incorporated into projects and collaborations that also served to promote young talent. In cooperation with the Faculty of Electrical Engineering and Computer Science at Hochschule Bremen, MAPEX actively supervised three bachelor's theses (see tabular form). A master's thesis, jointly supervised by both institutes, focused on the image-based processing and optimization of existing models.

The "Digital Materialities" project particularly contributed to promoting female academic careers, as one of the two postdoctoral positions at IWM was held by a woman, as well as the doctoral position affiliated with MAPEX.

## 5. Structures and collaboration

The structural partnership of a cultural and technical-historical institute, a materials science institute, and a media and learning psychology institute proved to be a highly effective collaboration for addressing the research questions in a meaningful way, as anticipated in the project proposal. While the creation of digital data was primarily the responsibility of the project partner MAPEX, the interpretation of the research data from both materials science and cultural studies perspectives brought together the expertise of this materials science partner and of the museum, leading to a new understanding of the objects. The investigation of the learning psychology potential of combining physical objects and digital replicas enabled close collaboration between the project partner IWM and DSM, particularly in the visitor surveys conducted during the special exhibition "X-ray. The Ocean." From both an administrative and scientific perspective, it proved beneficial to place the overall project coordination at the DSM. Since the work of the two partner institutes was largely based on the museum's collection and special exhibition, the museum played a key role as both initiator and mediator in the project.

The successful DSM and IWM collaboration extended to additional activities, such as a cooperation of both partners with TU Ilmenau on the salvage tug SEEFALKE, creating a virtually walkable application (AudioSEEFALKE), an initiative within the Leibniz "Medialität und Materialität" lab.

## 6. Quality assurance: Research Data Storage and Visibility

The project results are stored in three data structures of the National Research Data Infrastructure (NFDI), specifically in the databases MorphDBase, GFBio, and Kompakkt (https://www.gfbio.org/, https://kompakkt.de/explore), according to the nature of the objects and generated digital data. The 3D volume datasets, reconstructed from the scan data (the "digital raw material"), are made available to the research community as unprocessed reconstructions, while the image stacks collected in the project have been archived as such.

In 2024, DSM started virtual accessibility of a significant portion of its collection through its new platform "The Digital Depot." (https://digitaldepot.dsm.museum/projects/project002), by which users can access to the objects examined in the "Digital Materialities" project and gain new information on materialities and functions of these artifacts.

## 7. Additional resources

The DSM contributed extensive personnel resources to the "Digital Materialities" project (also see Tabular form). DSM press and public relations team participated in the project supporting publicity measures for the exhibition opening and its accompanying program. Furthermore, the museum's project management team dedicated to organizing the exhibition project "X-ray. The Ocean". The restoration and collections management teams were heavily involved in organizing the transportation of objects to Bremen and Tübingen. The museum's workshop management took part in meetings regarding the exhibition setup. Due to necessary cost reductions, the entire workshop team was responsible for constructing and building the exhibition setup. The education and mediation team was involved in the project through didactic consultation for exhibition design, the development and implementation of educational workshops, as well as the creation and execution of a visitor survey concept. Additionally, the practical implementation of the visitor survey in the museum was financially supported by the Leibniz transfer project "Platform for Advancing and Supporting Visitor Research in Museums," in which the museum is a partner.

## 8. Outlook

The existing web app ARtefact at DSM, which can be accessed on smartphones and tablets, was expanded to include the virtual 3D model of a ship's chronometer from circa 1835/1840 digitized in the project: https://3d.dsm.museum/ar_dev/#/models. This integration was made possible by the staff of the museum's digitization department and based on preliminary students work. Since the 18th century, ship's chronometers have played a crucial role in navigation, enabling accurate determination of longitude, thereby improving maritime navigation, nautical cartography, and – indirectly – facilitating new maritime expansion and globalization. In the ARtefact app, the chronometer case, which houses its intricate clockwork mechanism, can be virtually explored (**Fig. 14**). Nearly all mechanical components have been separated and animated, allowing users to see how they interlock logically, from the energy supply via a tension spring deep inside to the gears and the hands mechanism on top. Users can access texts and audio explanations that provide insights into the device's technical, navigational, and globalization-related significance. Additionally, an integrated quiz encourages users to engage with and further explore the virtual model. The 3D web app representation of the chronometer serves as an example of how data collected in the Digital Materialities project has been further developed and applied for educational and outreach purposes.

Although all subprojects successfully answered their research questions and the materials science-based study of museum collections has been strengthened, it is far from complete. The project results, presented in publications, conference lectures, and knowledge transfer events and applications, have led to new research questions and the need for further interdisciplinary collaboration between natural sciences, materials sciences, history, and cultural studies. This may, among other topics, include discussions on both the environmental and cultural heritage significance of fishing gear as present in museum collections.

---

Prof. Dr. Ruth Schilling
German Maritime Museum - Leibniz Institute for Maritime History

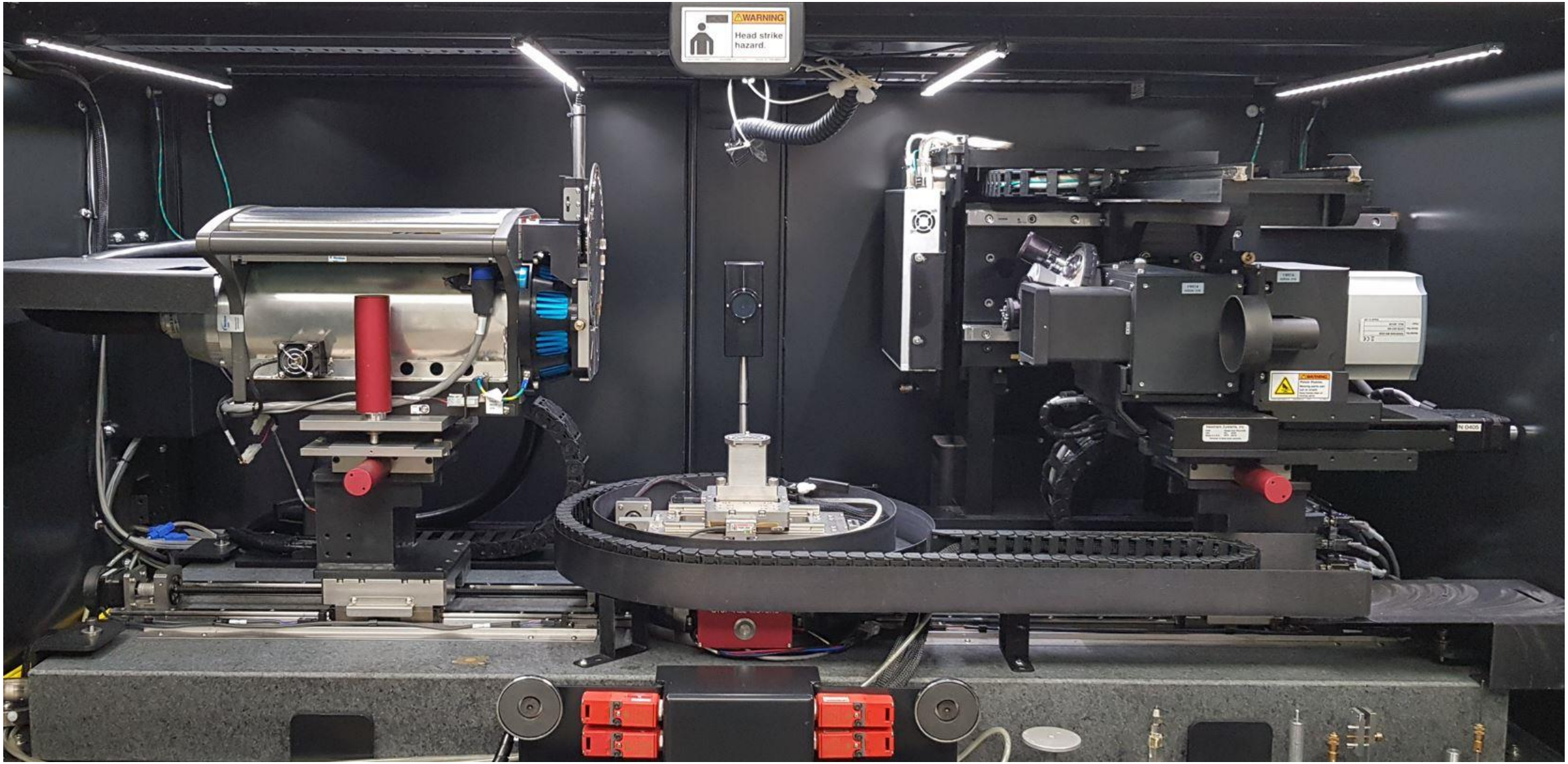
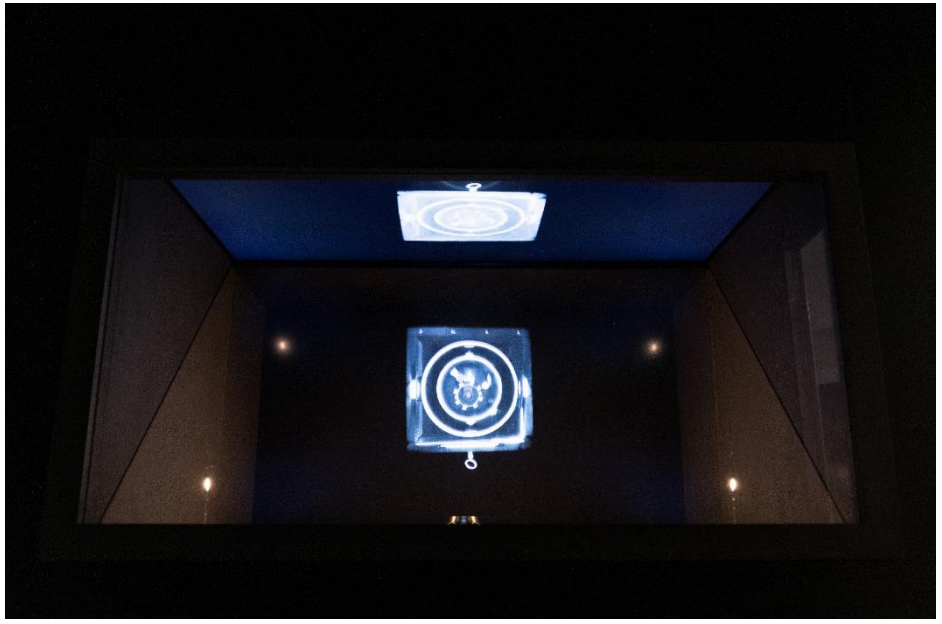



**Fig. 1** - 3D X-ray microscope, MAPEX Center for Materials and Processes, Photo: Frederic Theis/DSM.





**Figs. 2-5**
Special Exhibition „X-ray. The Ocean“ at DSM. Physical artefacts on the outside, virtual objects inside as a Pepper‘s Ghost pseudo-hologram. Photos: Nicole Werner/ DSM.


**Fig. 6**
Media station in the exhibition „X-ray. The Ocean“ displaying materials science observations of the exhibit objects. Photo: Nicole Werner/DSM.

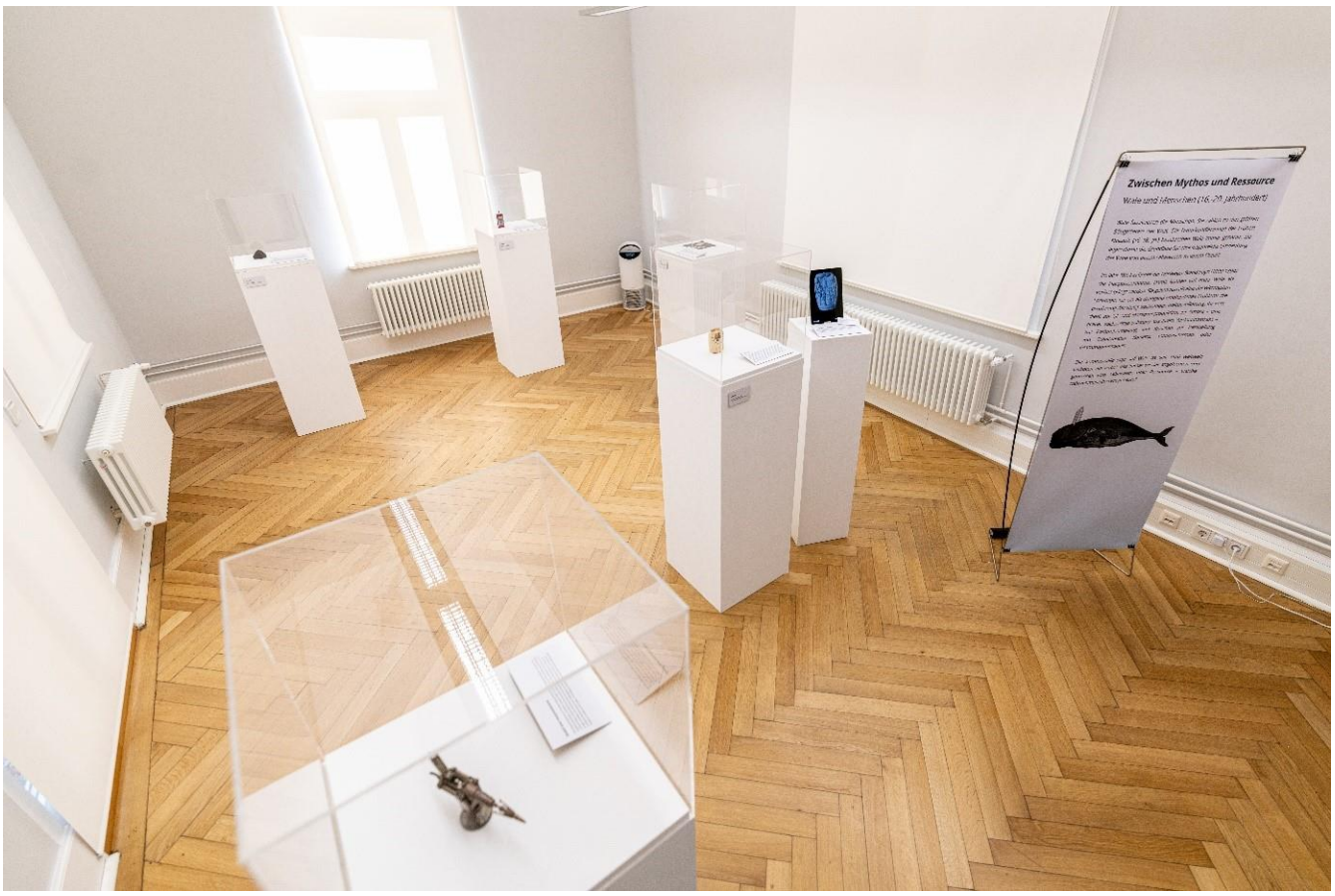



**Fig. 7** - Experimental exhibition "Whales and Humans" at the Leibniz-Institut für Wissensmedien. Photo: Christoph Jäckle/IWM, DSM, MAPEX.

**Fig. 8** - Excerpt from the second experimental exhibition “Whales and Humans,” featuring both real and holographic objects, presented using Microsoft HoloLens 2. Photo: IWM.


**Fig. 9** - Experimental exhibition “X-ray: The Ocean” at the IWM, volume models using Pepper’s Ghost technology and displayed on a regular screen. Photos: IWM / DSM / EZRT / MAPEX.

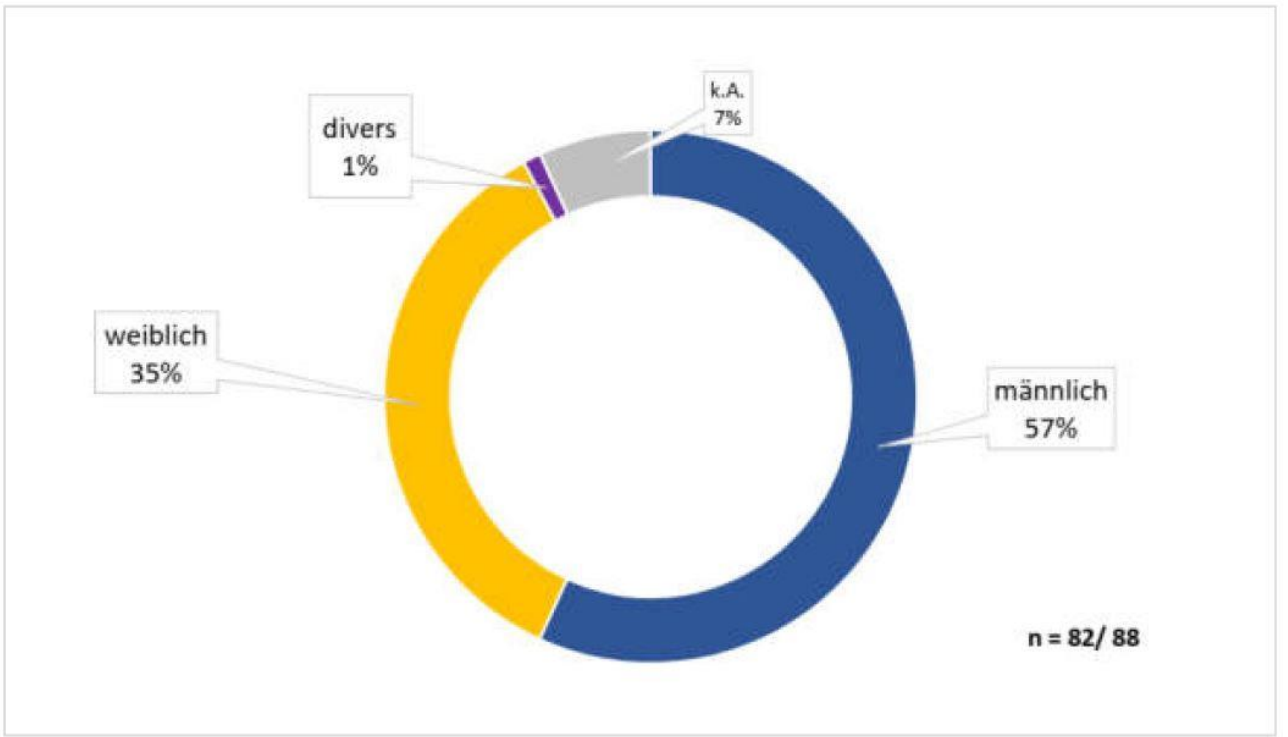



**Fig. 10** - DSM visitor survey in the “X-ray” exhibition. Gender distribution. Graphics: Jana Marks.

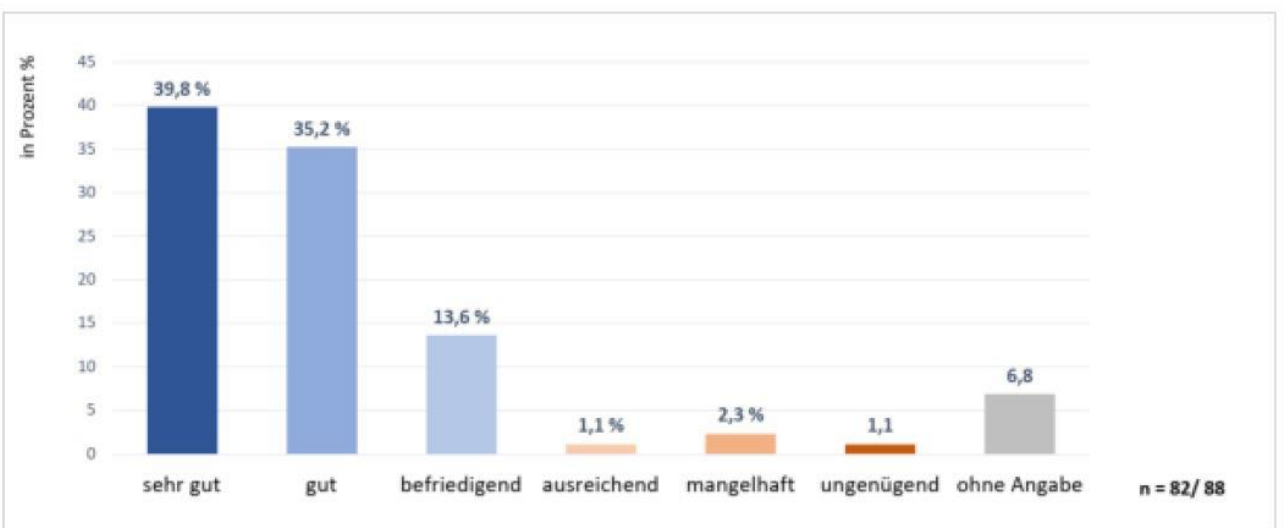



**Fig. 11** - DSM visitor survey in the “X-ray” exhibition. Overall assessment. Graphics: Jana Marks.


**Fig. 12** – Title slide of the popular science lecture “SEH-STÜCKE” Bremen. Graphics: Pia Götz/MAPEX.


**Fig. 13** - Visitor booth of the “Digital Materialities” project at the OPEN CAMPUS of the University of Bremen, June 2023. Photo: Frederic Theis, Data: MAPEX.

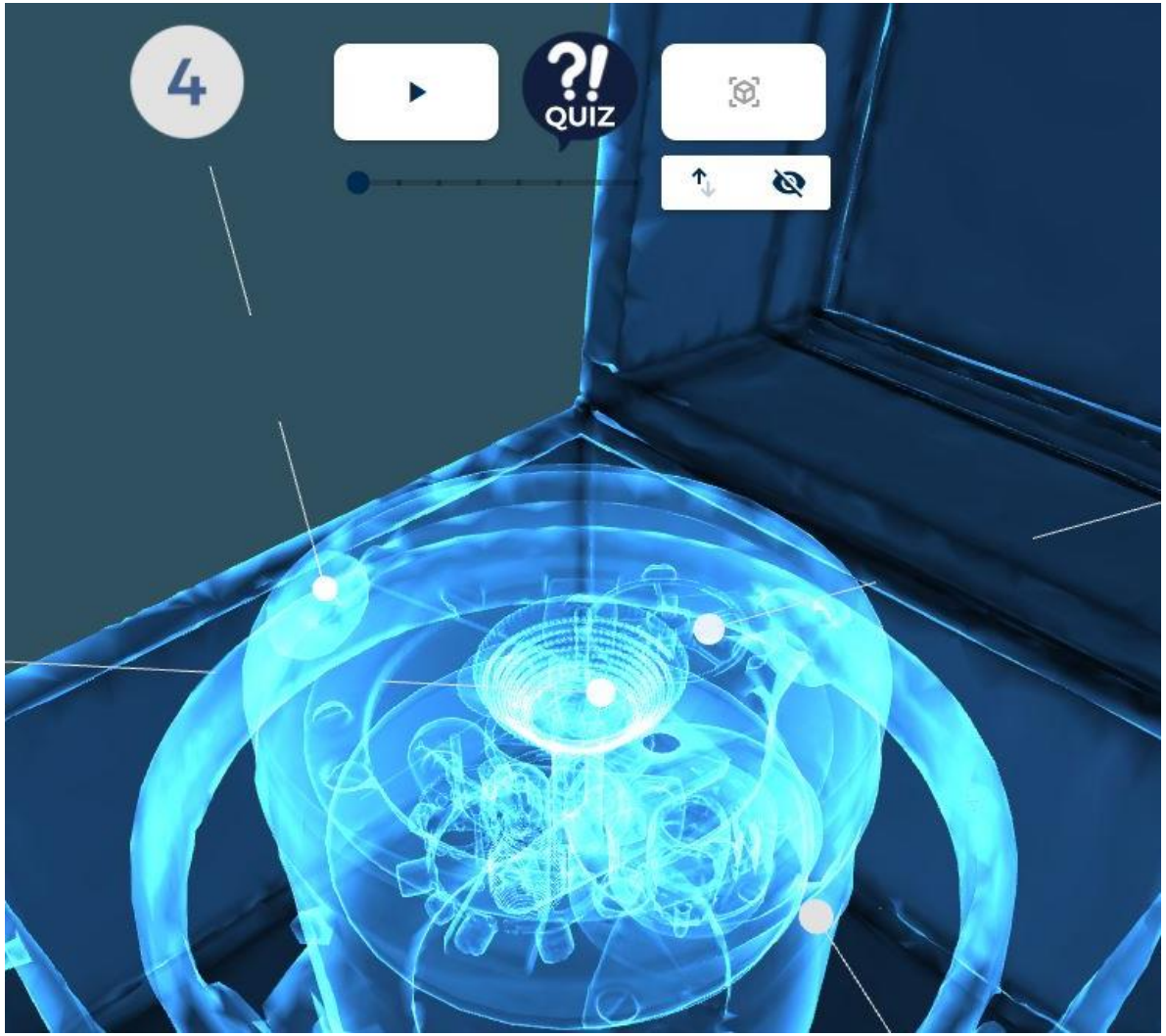




**Fig. 14** – Ship‘s chronometer in the museum app ARtefact. Programming and graphics design: Dennis Hoffmann and Luca Junge/ DSM. Raw data: EZRT, Pia Götz/MAPEX.