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# Digital Interaction with Physical Museum Artifacts

**Andreas Pattakos [1], Emmanouil Zidianakis [1], Michalis Sifakis [1], Michalis Roulios [1], Nikolaos Partarakis [1,*] and Constantine Stephanidis [1,2]**

[1] Institute of Computer Science, Foundation for Research and Technology Hellas (ICS-FORTH), N. Plastira 100, Vassilika Vouton, 70013 Heraklion, Greece; anpattakos@ics.forth.gr (A.P.); zidian@ics.forth.gr (E.Z.); misi@ics.forth.gr (M.S.); rouliosm@ics.forth.gr (M.R.); cs@ics.forth.gr (C.S.)
[2] Computer Science Department, University of Crete, Voutes Campus, 70013 Heraklion, Greece
* Correspondence: partarak@ics.forth.gr; Tel.: +30-281039-1754

**Abstract:** In the digital information world, visualizing information in public spaces has been implemented in various formats and for application contexts such as advertisement, useful information provision, and provision of critical information in the cases of accidents, natural disasters, etc. Among the different types of information displays, in this research work, the focus is given to the ones that extend the experience of people visiting cultural heritage institutions. To this end, the design and implementation of an interactive display case that aims to overcome the "non-touch policy" of museums are presented. This novel display allows visitors to get engaged with artifacts and information through touch-based interaction with the ambition to extend the target audience and impact of museum content. The conducted study demonstrates that the interactive display case is an effective solution for providing relevant information to visitors, enhancing their engagement with exhibits, and improving their overall experience. The proposed solution is user-friendly, engaging, and informative, making it ideal for museums and other public exhibit spaces.

**Keywords:** information displays; interactive information; public information displays; museum information displays

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## 1. Introduction

Providing sufficient information in the context of a museum visit is particularly important in the cases of museums where the objects themselves are not self-explanatory or host artifacts that are connected to the social and historic context of a social group [1]. At the same time, museums can be considered places where the diversity of the target visitors is extremely high in terms of background, cultural knowledge, attitude towards the visit, age, language, etc. [2–4]. This has resulted in the proposal of several forms of information personalization to fine-tune the services of the museum to the individual visitor's profile [5–8]. Lately, such possibilities have also been explored in more open museum experiences such as in the open air and ecomuseums where the combination of mobile devices, localization, and recommendation systems may provide novel forms of personalization [9,10].

An alternative to profile-based content personalization is motivating visitors of the museum to interact with information and digital content through various forms of immersive experiences (e.g., [11–13]). These experiences can augment existing museum content and artifacts or provide alternative content [14]. At the same time, a new trend is to provide novel experiences enhanced with storytelling and narratives [15], inviting the visitor to be engaged in the museum metaverse [16].

In this work, we provide an overview of the design and implementation of a new form of display for museum artifacts. The main objective of the display is to connect user interaction with the artifacts with storytelling content that reveals the social and historic context of each artifact. By generalizing this objective, the display proposed comes with an authoring environment and multimedia content rendering engine to support its easy optimization to any form of museum artifacts.

In our use case, biographical artifacts were used that relate to the personalities of the Greek Revolution in the context of the installation that occurred during the great anniversary exhibition for the Revolution of 1821 entitled REVOLUTION '21 REFRAMED, organized by the National Historical Museum of Greece. The rest of this article is structured as follows. In Section 2 we present background and related work on information displays and interactive museum artifacts highlighting the contributions of this research work. The design of the physical enclosure for the ICT equipment is presented in Section 3, followed by the implementation of the software in Section 4. The validation of the evaluation of the system before its official installation is presented in Section 5. The article concludes with a discussion of the results of this work.

## 2. Background and Related Work

### 2.1. Information Displays

Digital signage brings together various market players, all of which have different objectives and expected benefits. For this reason, it has been a domain of research in economic science. In this context, researchers are proposing frameworks for digital signage that would allow the development of various business strategies and associated business values [17]. At the same time making such information displays interactive has been studied since most of these displays are based merely on the provision rather than interaction with information [18].

The study of user motivation, content consumption, and engagement are directly relevant to their usage of information displays for advertisement, product display, and multiple forms of information providers such as in airports, train stations, etc. In this context past research has shown that audience expectations towards what is presented on public displays can correlate with their attention towards these displays. Similar to the effect of banner blindness on the Web, displays for which users expect uninteresting content are often ignored [19–21]. Other researchers have highlighted the fact that the effectiveness of digital signage messages that contain aesthetically pleasing sensory-affective cues is higher than the ones that present more functional content [22].

At the same time, the types and form factors of such displays seem to have an impact on their utility. For example, chained displays, have been proposed as a combination of several screens to create different form factors for interactive public displays [23]. At the same time, more provocative types arise such for example free-standing displays [24–27], personal displays [28], mobile devices [29–31], interactive shopping displays [32–34], and even battery-free patched wearable displays for opportunistic interactions [35]. Recently, more exotic forms of information displays are under research to support the full-color holographic presentation of visual information [36,37].

### 2.2. Interactive Information Displays

Recently a significant amount of research work has been focused on the domain of information visualization, mainly focusing on the alternative means and strategies for visualizing big data [38–44]. At the same time, the type of visualization and the visualization medium has been proven to be of extreme importance and several attempts have been made to utilize different presentation mediums, display formats, and interaction types [45–50]. Inevitably interaction with such data is required for the user to submit data queries and view and interact with results in a more attractive way [51–55]. At the same time, in the case of public information displays, privacy is also important [56].

### 2.3. Interactive Museum Artifacts

In museums today, digital technologies are increasingly integrated into diverse practices of collection and collections management, information management, curating, exhibiting, and educating [57]. This need was made more urgent due to the COVID-19 pandemic [58,59]. At the same time, especially in the domains of exhibiting and educating, modern methods based on interaction design, interactive storytelling, and artificial intelligence have been employed and paradigms for museum experience design have been proposed [60–62]. A survey on virtual museums has depicted the following technology-types of the virtual museum [63,64] (a) enhanced imaging [65], (b) virtual reality exhibitions [66–70], (c) augmented reality (AR) and web-based AR exhibitions (e.g., [71–74]), (d) Web3D exhibitions (e.g., [75–79]), (e) mixed reality (MR) exhibitions [80–85], (f) haptics (e.g., [86–90] and (g) mobile devices in museums (e.g., [91–96]) and (h) accessible virtual museums (e.g., [97–100]). Among these, interactive museum artifacts are blending bits and pieces from the aforementioned technologies to provide unique interaction and storytelling experiences (e.g., [101–106]). At the same time, the museum content is expanded to support aspects of intangible cultural heritage including the oral tradition, festive events, recipes, social events, and craft practices (e.g., [107–114]).

### 2.4. Contribution of This Research Work

In this paper, we present the design and implementation of an interactive display case for museum artifacts, that breaks the barriers of the "non-touch policy" of museums. Museum artifacts are placed in a glass display and the users can touch the glass right on top of each artifact to select the object upon which they wish to get more information. This display is complemented by a large screen where users experience multimedia content relevant to their selected artifact. In this way, the users are welcome to engage with artifacts and digital information in an interactive learning dialogue. Furthermore, through targeted multimedia content production, we can bind the artifacts with storytelling techniques since in the use case each artifact is connected with a video production thus suspending the disbelief and providing a transition to the past to reveal the story of each artifact.

The major benefit of the proposed approach concerning other relevant research outcomes is that it is complementary to the museum experience. Most of the relevant works have focused on extending the museum experience by creating another form of digital encounter by facilitating various technologies such as AR, MR, VR, etc. The main distinction of this research work that makes its exploitation easier is that the museum structure is principally the same and it enhances the physical items of the museums with digital dimensions. As such it can be conceived as a more interactive way of accessing information from the exhibit labels. Furthermore, instead of proposing a new virtual world or virtual experience, it provides interaction that leads to forms of content which are more easily accepted by museums such as information videos and photographic documentation.

## 3. Design of Information Display

Museum displays often provide limited information about the objects on display, making it challenging for visitors to understand the context and significance of exhibits without additional guidance. To overcome these issues, we designed an interactive display case that provides contextual information using a transparent touch glass. The system allows visitors to interact with exhibits through touch and instantly learn more about them. The project was inspired by the need to create an interactive display case for a glass case of antique weapons from the Greek Revolution of 1821.

Regarding the design of the display case, the main requirements that were considered were the robustness of the construction, the integration of technology within the shell of the display, and the self-contained ability of the entire exhibit for it to be easily installed and maintained. To this end, the industrial design of the display aimed at creating a common container for both the technology and the display case where the artifacts are placed. In this way, technology is designed to be integrated within the container of the display case and thus does not affect the design aesthetics. To do so, the design of the display is oriented towards generating the negative space needed to host the equipment as shown in Figure 1a,c.

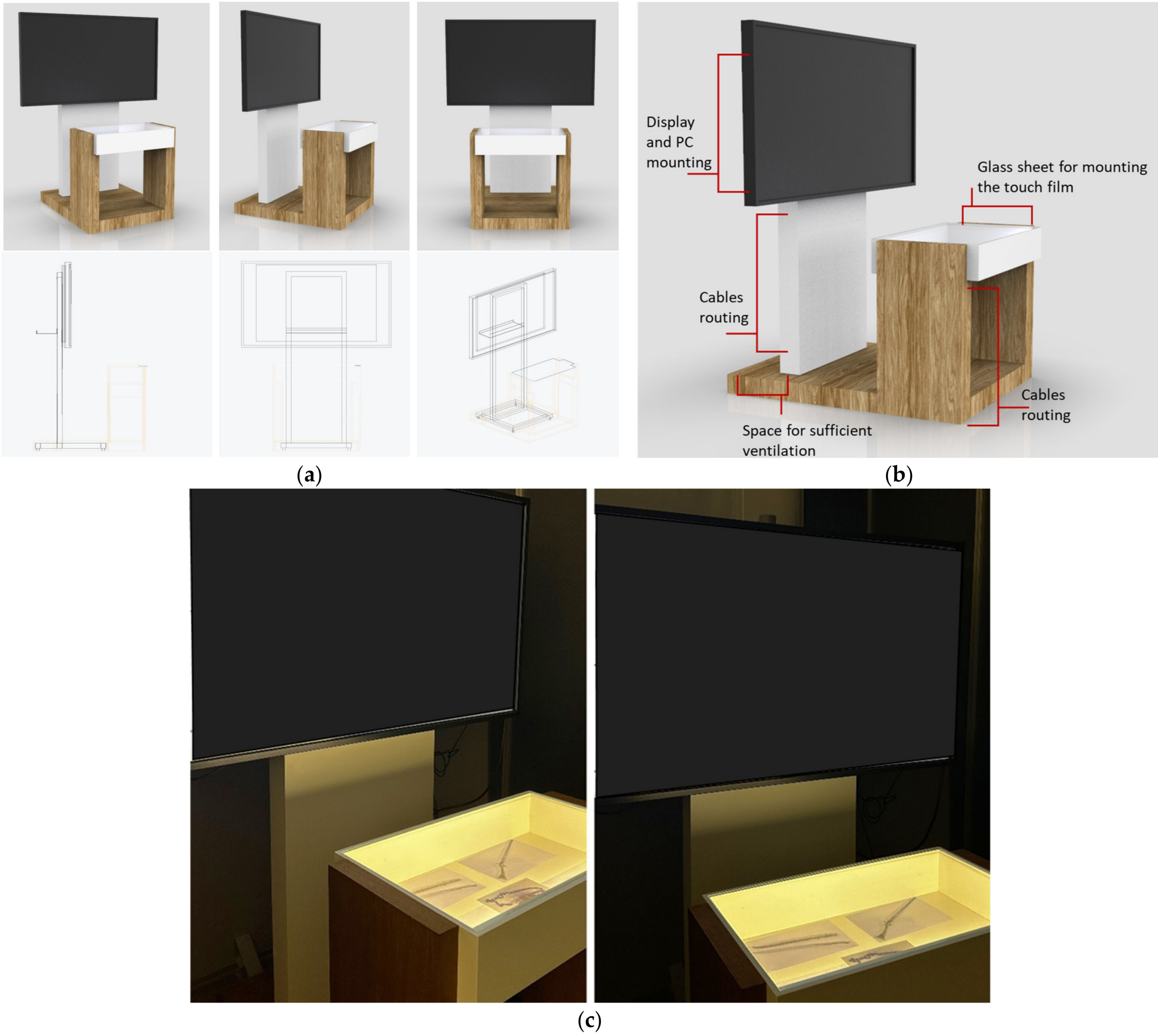


**Figure 1.** Display design (**a**) photorealistic and wireframe renderings; (**b**) analysis of negative space of the display case where equipment is integrated; (**c**) implementation of the prototype.

The design of the display was conducted in CAD software and integrates sizing, materials, analysis in parts, and cutting dimensions which are straightforward to be implemented by standard construction methods used in small and medium-sized wood and metal construction workshops (see Figure 1b). The next step was to create a prototype of the display for the functional validation of the concept to act as a testbed for the software development iterations.

## 4. Software Implementation

The software of the interactive display case can be considered as two applications one for the association of content to specific parts of the touch glass case, and another one for the visualization of the associated information when a user touched the corresponding part of the exhibit. This approach allows the display to be easily adapted to different exhibits and contents offering at the same time a seamless interaction experience to visitors.

As shown in the system's architecture (see Figure 2) a state manager is used to define the state of the system and thus control which application currently has the user's focus. Based on the focused application, the input controller which is a high-level wrapper of the Windows touch device built on top of the device driver of the touch foil translates touch inputs into touch points or touch areas. Touch areas are used in authoring content areas while touch points are translated to selections of areas in content presentation mode. With simple and intuitive architecture, we manage to combine the functionality of the two applications into one software to be easily installed maintained and used by end users.

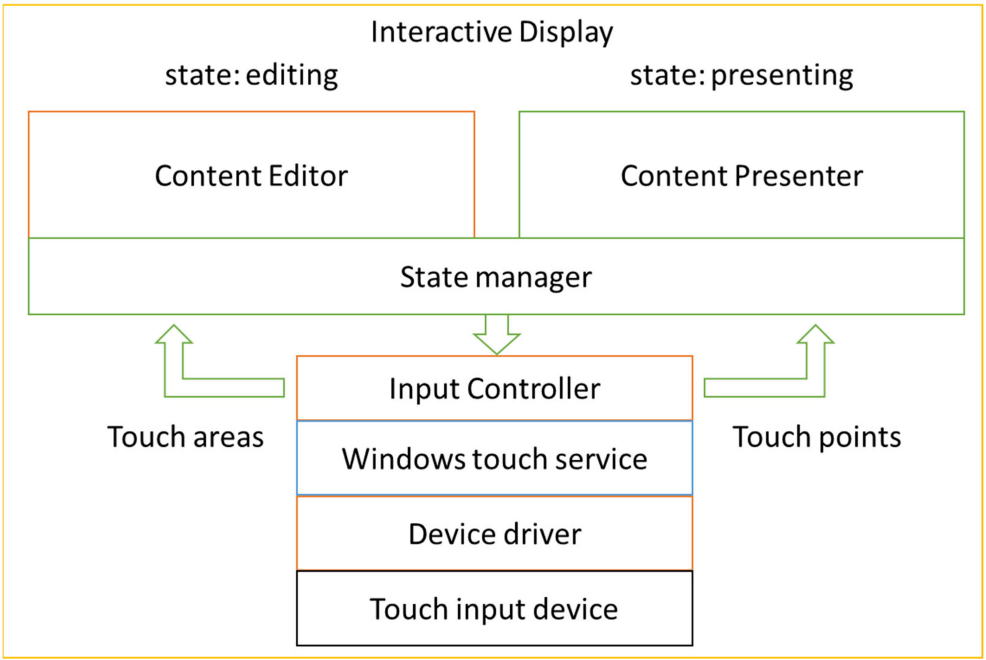


**Figure 2.** System architecture.

As analyzed above, having two separate applications for content association and information visualization in the interactive display case can increase overall complexity and installation challenges. To this end, for the implementation, we used the Unity 3D game engine [115] which provides a versatile environment that can handle both low and high-level interaction concepts. Furthermore, by leveraging Unity's versatile environment, we can merge these two applications into a simpler and more manageable setup. With a general manager implemented in Unity, we can easily monitor and switch between the applications in real time.

In addition to its versatile environment, Unity also includes a device communication layer that enables seamless communication between hardware devices and the software running on the display case. This layer can accurately translate touch controller inputs into x/y coordinates, enabling the display to respond immediately and accurately to user interactions without any added latency. This precise touch input tracking provides visitors with a seamless and intuitive interaction experience, making the exhibit engaging and memorable.

By integrating Unity into the display case, we can not only simplify the installation process and improve the user experience but also take advantage of Unity's vast library of tools and assets to enrich the interaction between the visitor and the exhibit, and the flexibility to continue enhancing and evolving the exhibit to meet the ever-changing needs and expectations of our visitors.

### 4.1. Content Creation

The content creator tool supports the assignment of multimedia content to specific bounding areas of each exhibit within the display case. Creating a new exhibit is as simple as drawing the bounding area on the touch glass case to define the exact position of the exhibit. As the user draws the area, a line renderer follows the touch position to display the drawing. After the area is drawn, the system fills in any gaps and creates a mesh collider of the same size as the area for the content viewer to identify later. The system then prompts the user to provide all the necessary content information, such as file paths for Greek and English content, timers for static images, and any sequential content desired after the initial content is finished. By default, the sequential content is set to the introduction content. The entire workflow is presented in Figure 3.

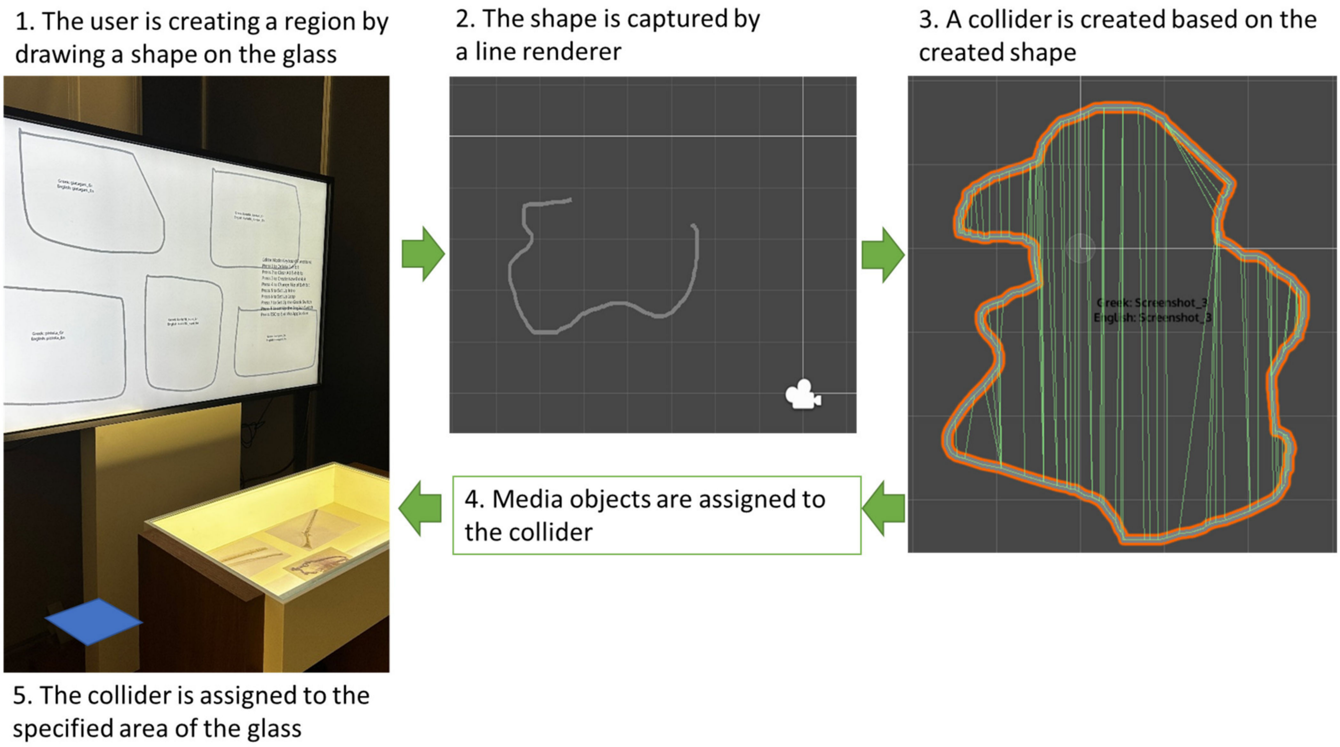


**Figure 3.** The user is touching the glass display to create an interaction area and Unity translates touch inputs to a line segment which is used to create a mesh collider which is assigned by the user with multimedia content.

The system not only allows for the creation and management of exhibit content, but also provides additional useful functions such as language switching. To set up a language switch, the museum curator defines the bounding area on the touch glass case in a similar manner to creating a new exhibit. Instead of content, however, the system assigns an event function that toggles the language between Greek and English. This feature enhances the accessibility and engagement of the display, allowing users to easily switch between languages while exploring the exhibit. With the flexibility and ease of use provided by these system functions, museums can create immersive and interactive exhibits that cater to diverse audiences.

Overall, the content creator streamlines the process of assigning and managing exhibit content, enabling coordinators to easily create interactive displays with rich multimedia content.

### 4.2. Content Viewer

The content viewer serves as the primary interface for end users to interact with the exhibits displayed in the case. Its primary functions are to detect user interactions and display the relevant content based on those interactions. When a user touches the touch glass, the content viewer receives a signal containing the precise coordinates of the touch event in relation to the rest of the glass. Using Raycasting, the system searches for any exhibit colliders that intersect with the touch point. If an exhibit collider is found, the system retrieves and displays the content associated with that specific area on the secondary display. Once the content has finished playing, the system checks for any sequential content to play. If none is found, the system will display the introduction content instead.

An example of the in-lab set-up of the working prototype is presented in Figure 4.

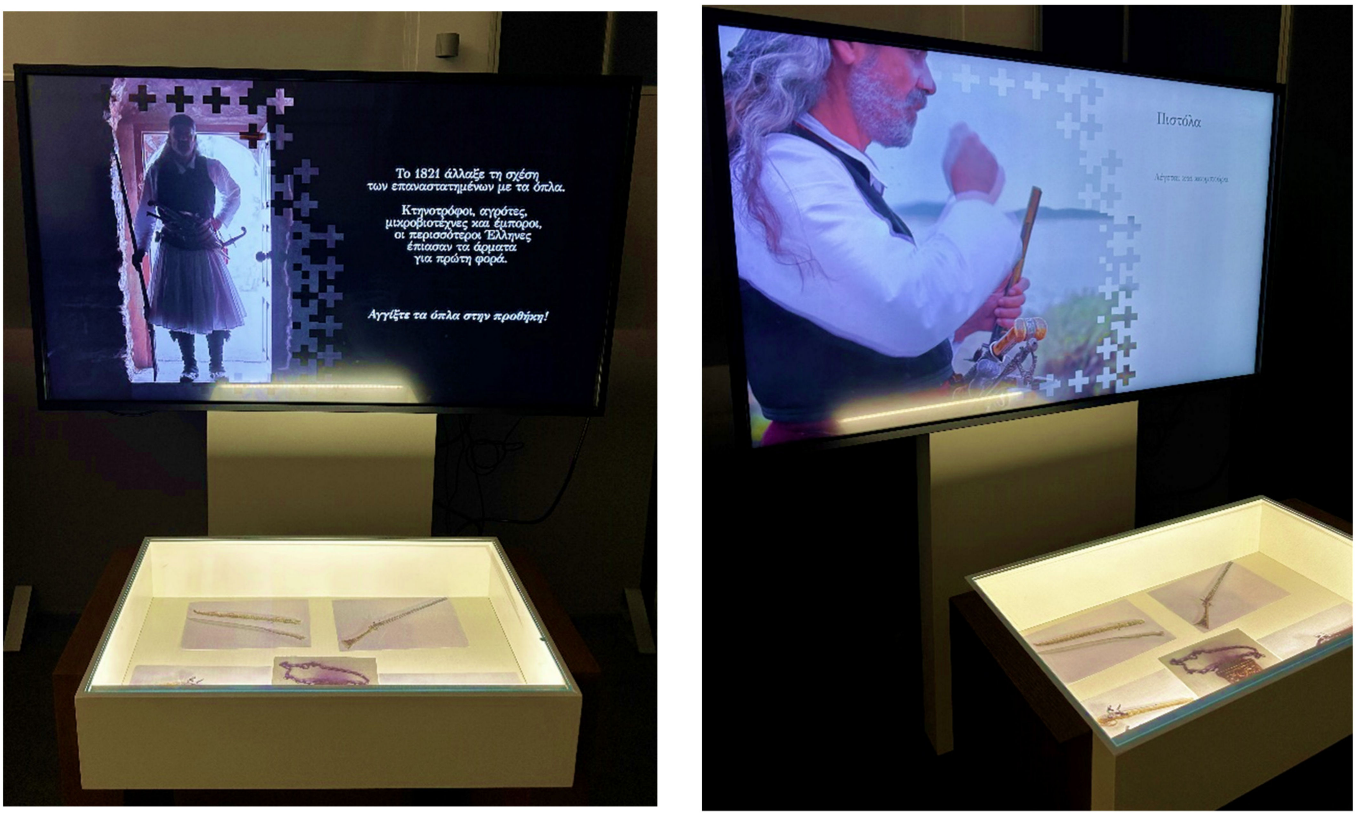


**Figure 4.** Content viewer in-lab prototype presenting information upon the selection of the assigned information areas (in the left side of the screen information regarding the exhibit and how to initiate interaction are provided in Greek).

## 5. Validation–Evaluation

Creating interactive applications that will be available for use by hundreds of visitors requires that several aspects have to be considered before the deployment of the solution. With this in mind, the validation of this work has been performed in a laboratory environment where an actual prototype of the system was created. The design of the prototype is discussed in Section 3 and for the validation, we moved to implement an actual physical prototype of the installation. This physical prototype acted as the test bench for application developers, and it was critical for testing the functionality before production. In this test bench all the ICT components were integrated and several touch-based interaction techniques were evaluated before going with the solution of the touch film since all computer vision-based solutions had severe problems due to external lighting, illumination, and reflections from the glass, etc. In this context, the test bench was used both for the selection of the appropriate technologies and for the validation of the software. In terms of software validation, it was important to validate the efficiency of the administrative, and authoring interface and the quality of recognition in terms of success rates. A critical factor was to test that the perceived bounding box of the curator is translated accurately to regions of the screen and their correspondence with museum artifacts within the display.

The validation process took several iterations where a different version of the hardware and software setup were tested. These tests were performed mainly by technical personnel and the objectives were to validate that the integrated technology provides the appropriate features and that it operates as expected in various conditions. This validation was conducted before evaluating the authoring and interaction application.

Regarding the evaluation of the prototype, this was carried out iteratively using two user groups. The first group was comprised of usability and user experience experts that evaluate an interactive application based on the Heuristic Evaluation method [116], which is an expert-based review method that is highly beneficial to eliminate usability problems before testing with representative end users, [117,118] also taking into account evaluation methods targeted on museum experience [119,120]. A small group of evaluators examined the user interfaces to spot violations of established usability principles, commonly known as heuristics [121]. To find heuristic violations or other usability issues pertinent to the system, the evaluators performed multiple iterations. Each evaluator recorded the identified problems and specified the violated principles for each one. Then, all evaluation reports were combined into a single one, addressing each problem exactly once. To prioritize the problems, the evaluators reviewed the combined list and gave each problem a severity rating. The problems' final severity score was determined by averaging the results of each evaluator.

Results in each iteration highlighted usability problems that should be rectified, ordering them by severity. Given the multiple iterations, numerous problems were identified and corrected until a prototype was identified as usable. These evaluation iterations can be considered part of the development process since they are interwoven with this process. Each iteration results in an updated version of the system and continues iteratively until all comments are satisfied.

This section summarizes key issues identified during evaluation/lessons learned regarding the interactive display:

- Buttons or interaction areas in the case of the display that are relevant to a specific context, such as the areas of interaction on the glass, should be easily associated with the specific exhibit to which they are relevant, by placing them at an appropriate screen location ensuring that the diagonal viewing angle of the visitor will not affect his/her perception of the interactive area.
- There must be some form of feedback from the system upon the selection of an area of interaction. In the earlier versions of the system, this was done silently resulting in some cases of frustration regarding which area is activated. Auditory feedback was introduced to cope with this issue.
- Regarding language changes, it was requested that some form of typography should be integrated into the surface of the display so the visitor to easily locate the interaction areas for language switching.
- The user must be constantly informed regarding which artifact from the physical display is selected, to have a constant association between content and artifact. The evaluators proposed that led lighting should be introduced within the display in the form of a grid to be able to activate only the lights that are within the selected region of a specific artifact.

The second user group was the users of such an application. For this, user group co-workers with expertise in diverse fields were used (a social scientist, an anthropologist, a philologist, an English teacher, and a performing arts director). These users were invited to interact with the system each one assuming the role of the visitor. This evaluation was mainly content based thus, experiencing the provided interaction and content to judge user experience. Mainly we received positive comments on both aspects. All users were very impressed by the new form of interaction and positively judged the quality of the museum content which provided a storytelling dimension through the dedicated production of historic videos.

## 6. First Commercial Setup of the Display Case

The first commercial setup of the display case was conducted for the great anniversary exhibition of the Revolution of 1821 entitled REVOLUTION '21 REFRAMED, organized by the National Historical Museum of Greece in the Old Parliament House in Athens as part of the celebration of 200 years since the beginning of the Greek Revolution. The central anniversary exhibition highlighted the ideas, causes, persons, events, and results of the Greek War of Independence, as they were formed through conflicts and compositions of different interests and traditions.

The display case presented historical weapons and other relics of the Revolution. The success of the system was so wide that the National Historical Museum decided to include it in the permanent collection of the museum and thus since 2021 it has been accessed and used by tens of thousands of visitors.

The design of the final product was an adaptation of the initial design to address the need for a larger display case and 65 inches display as shown in Figure 5.

**Figure 5.** The setup of the display case in the National History Museum of Athens.

## 7. Conclusions

In this work, we designed and implemented an interactive display case to overcome the "non-touch policy" of museums and allow visitors to get engaged with artifacts and information. Thus, we are extending the audience and impact of museum content. We consider this the main contribution of this research work since it keeps the artifacts in focus while augmenting their existence through interactive features that are linked to further information.

The main solution that was followed during the construction of the display and after experimenting with several computer vision-based approaches was to mount a touch film on the glass top of the display and create a dedicated software capable of assigning regions of the glass top to physical objects within the display. Then, by touching each region multimedia content assigned to this region is reproduced. To ensure the reusability of the display case we have performed the industrial design of a solution that can be considered as a generic interactive display case complemented by an authoring software and content renderer. Thus, the setup of any such display can be performed easily through the content creator app. The resulting design was implemented as a prototype before its first installation for development purposes and the validation of the proposed solution in the lab. After the successful validation, the first commercial installation occurred during the great anniversary exhibition for the Revolution of 1821 entitled REVOLUTION '21 REFRAMED, organized by the National Historical Museum of Greece. We are particularly happy that due to the success of this exhibition, the display case is now part of the main exhibition of the museum since it was selected as a permanent exhibit for the museum.

The design process followed can be considered close to the one followed by commercial implementation considering that we followed all the steps of designing a product and performed its validation and proof of concept prototyping. Thus, we were able to transform research efforts into providing richer interaction with museum artifacts in a non-obtrusive way into an actual product experienced by thousands of people. In this process, we followed an approach of keeping innovation in the interaction style and project concept and trying to adapt it using standard ICT equipment to ensure that the final result could support trouble-free interaction under the restrictions posed by the need to implement a public information display.

To do so we implemented an actual prototype of the installation for development validation and evaluation purposes. Validation was conducted in the lab to ensure the appropriate functioning of the equipment according to specifications. The evaluation was performed in two phases. The first phase involved usability experts to improve the interaction with the system and the perceived ease of use. This resulted in several modifications in terms of hardware, software, and setup. The second phase involved a small set of users with different backgrounds to evaluate the device function and content in simulated museum usage. After concluding with both phases, which resulted in the adaptation of the software and hardware part of the system, the museum installation was conducted. Supplementary Materials in the form of a usage video are available through zenodo [122].

By concluding this research work, we are confident that through this paper the main concepts under the creation of an interactive display for museum artifacts will support the further exploitation of the proposed concept from its creators but also from the cultural and creative industries in the context of new museum applications and services. Regarding future improvements to the display, we are focusing on the following directions. The first regards the enhancement of visual feedback on the selected artifact within the display. The second regards the implementation of a richer UI application that combines with a multi-touch screen to enhance the information sources that can be assigned and becomes interactive for each artifact on display.

**Supplementary Materials:** The following supporting information can be downloaded at: https://we.tl/t-z399gGd3Nc (accessed on 15 March 2023), A video presenting the final result as integrated into the main exhibition of the National History Museum of Athens is available at zenodo [122].

**Author Contributions:** Conceptualization, E.Z., M.S. and M.R.; methodology, E.Z.; software, A.P.; validation, E.Z., M.S., N.P. and C.S.; formal analysis, E.Z. and M.S.; investigation, E.Z., M.S., N.P. and C.S.; resources, M.S. and M.R.; data curation, M.S.; writing—original draft preparation, N.P., A.P., E.Z., M.S. and C.S.; writing—review and editing, N.P., E.Z., M.R. and C.S.; visualization, A.P., M.R. and E.Z.; supervision, E.Z., M.S., N.P. and C.S.; project administration, E.Z.; funding acquisition, M.S., E.Z., N.P. and C.S. All authors have read and agreed to the published version of the manuscript.

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