# Evaluation of Adaptive Interaction Systems for Virtual Museum Development

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### Abstract

Virtual Museum (VM) is an application of Virtual Reality (VR) technology generating realistic visualization and sensation to convince museum visitors to interact with digital content. There are many immersive VR devices that support interactive VM applications. We investigate appropriate devices for interaction within VM. We proposed a Storytelling platform to achieve device organization without modification, the story and interaction were self-adapted to the selected device. Three types of interactive content were designed on our Storytelling platform to be applied on different interaction systems: a 2D standard display, a 3D stereoscopic display and a full immersive CAVE. The results showed different performances of each system supporting VM developers to select an appropriate interaction system. The evaluation contributes to the design of content and interaction of VM development with more efficiency based on user requirements.

**Keywords:** Virtual Reality, Virtual Museum, Human Computer Interaction, Storytelling

### Introduction

Virtual Museum (VM) is a museum application about cultural heritage and entertainment using Virtual Reality (VR) technology. Many low-cost and high-performance devices are used for their applications to immerse museum visitors to the provided content. The use of immersive VR technology is a trend for VM and impacts on user experience. The Last Supper Interactive project [1,2] was one of the 1st full immersive experience for VM (perspective performance of Leonardo Da Vinci). It provoked the study of the project development to make this content attractive and meaningful. Indeed, to tell the story and to interact with it. Many tests were made to find which device could be efficient to support the Last Supper virtual experience. Intuitiveness allows museum visitors to enjoy a drastically different experience. The combination of interactive content and immersive VR in VM makes user interest for their provided content and improve gained knowledge. The results of visitors study on VM [3] showed that virtual environments and interactive content were both important elements for learning approach. Moreover, the study of effectiveness of immersive environment indicated that cognitive involvement increases [4] when interactive content was used to VM applications. Using interactive content is a better way to educate, entertain and engage visitors in VM to convince them to learn about the provided story. Constructivist learning can be supported when visitors control content by themselves which stimulates visiting motivation [5].

VMs were divided into 5 categories [6-8]: Digital media VM, online VM, interactive Web3D VM, mobile application VM and interactive on-site installation VM. Each type has different patterns of development and interaction with different users depend on technologies and devices used to access the virtual environments in the VM. We observed that all of them were device dependent platform. Especially, on-site installation is the type of VM where VR technologies are used and play an important role for VM development because high level interaction is expected. Devices are connected to VM application as the tools to interact with content. Therefore, the system used to develop the VM application was based on the selected device and the structure of the application was device dependent. When the VM application was developed, changing device was not easy. Without modification, the system was not compatible with the original application when switching to a new device. In order to deal with this problem, we introduced a device-independent VM development. VM applications should not depend on

the device. The content of applications must be used with a new device without changing its structure. The device-independent platform was designed to support this concept.

The design of VM application and interaction system were evaluated using device-independent platform. Different stories were prepared to study user engagement on each content style and also to investigate needs of interaction. Device usage and performance were observed for different interaction system. The results of this study support us to re-design the content as well as to identify user's behavior on each interaction system. The final goal is to contribute to a better immersive museum experience for visitors.

**VR toolkits**

Virtual Environment (VE) and devices are components of interactive on-site installation the type of VM which provides interacting with the content. Design and development of VM therefore take into an account of interaction allowing users to learn the content they are interested in [9]. During VM application development, immersive devices must be connected together to boost up the device abilities to enhance realistic graphic or other capabilities through technical process. A VR toolkit was used to connect devices to interact with the VE. It was a complete solution that covers the process of preparing, adding interaction, adding animation, viewing, and distributing 3D models to create VR experience. It has a group of Application Programming Interfaces (APIs) that implemented multiple domains of resource and extends them with various tools. The key features of the VR toolkit were VEs creations and device interfaces to create connections between devices and VE. Following examples were VR toolkit and related platform for VR application development and can apply to use in VM development.

VRUI (Virtual Reality User Interface) was a C++ development toolkit for highly responsive and interactive VR applications aimed to create completely environment-independent software [10]. VRUI applications work with an intermediate tool layer that expresses interaction with input devices at a higher semantic level, which separates applications from the input devices available with any environment. System integrators provide input devices that are available at semantic level such as location selection, drag, navigation, menu selection, etc., using the most efficient and easy-to-use method. By this reason, VRUI applications work effectively in a wide variety of VR systems ranging from desktop systems with keyboard and mouse to fully-immersive multi-screen systems with multiple 6-DOF input devices. VRUI cannot provide a device independent framework because application behaviors were implemented as specialized tools for each device. If an application has some behavior to be invoked, the developer must create a corresponding tool class to device, VRUI did not support it directly.

VARU [11] was an integrated VR and AR framework designed to make the development of a tangible space application easier and more efficient. Depending on the available resources, the application developer could design an application which involves virtual, physical, or mixed spaces. A single object may have multiple representations in the different interaction spaces. Instead of defining them as multiple objects, they introduced the extension to handle the object consistency across the different interaction spaces. This makes the object management across the different spaces easier to maintain and easier to extend to another interaction space. This toolkit is implemented to explore different types of mixed-space collaborations and take advantage of the benefits of each collaboration type.

FreeVR [12] was an open-source and a cross-platform support for multi-processing. FreeVR was compiled on various platforms which were suitable for use in highly immersive environments deployed in many device interfaces. The goal of FreeVR was to facilitate VR applications to be shared among active VR research sites using different hardware. However, FreeVR was not a VR content library which does not provide a scenegraph layer, or other features often associated with such libraries like intersection testing and collision detection. It does not provide a physical simulation for objects in the virtual world.

CalVR [13] was a VR middleware system. It was implemented through an object-oriented class hierarchy which supports non-standard VR systems such as auto-stereoscopic displays, as well as multi-user support for viewing and interaction. It has several built-in navigation methods, an extensible 3D menu system, and supports a variety of 3D display and tracking systems and also collaborative work at different network-connected sites. However, this toolkit focuses on device connections rather than content design which is another part of VM development.

RUIS (Reality-based User Interface System) [14] attempted challenges of interfacing with exotic VR devices and their equally exotic drivers. It relies on low-level input data, issues with compiling software and linking programming libraries, etc. VR applications commonly use a 3D user interface (3DUI), where the user operates in a spatial 3D context involves the 3D position tracking and orientation of user's hands and head. RUIS toolkit provides 3DUI building blocks for creating immersive VR applications with spatial interaction and stereo 3D graphics, while supporting affordable VR peripherals

like Kinect, PlayStation Move, Razer Hydra, and Oculus Rift. RUIS implements a spatial interaction scheme that combines free-form, full-body interaction with traditional video game locomotion.

Game engines are also platforms that support creating VR or VM application. Unity3D and Unreal Engine 4 (UE4) are game engine enabling VR application development. They allows the connection of some VR devices directly from their engine providing a base API and features set with compatibility for multiple devices. These game engines are designed for realistic visualization and provides a solid foundation to build content on most VR platforms. Advanced optimization designed for high performance, CPU/GPU profiling tools and flexible renderer equips developers to efficiently achieve quality VR experiences. With these capabilities, VR and VM applications can be easily designed and developed using the game engine [15]. However, game engine was designed specifically for video game development. There were limitations on accessing specific VR devices and switching devices. Interaction within VEs were defined for the selected device in advance.

The purpose of VR toolkit is to provide reusable components that can be used to create VR applications by avoiding starting from scratch. It reduces the amount of programming effect. VR toolkits may include functions for handling, displaying, distributing, or managing input devices. This includes the ability to use the application and access low-level devices. This is a design that can be applied to the on-site installation VM that focuses on user interaction. However, these features were the basis of the VR application development. Especially, when considering the properties of the VM narration, the VR toolkit did not explicitly support this feature. It lacked VE design that emphasizes interaction between 3D objects leading to a platform to support story making with an adaptive interaction system. To enhance the development of VM application in the context of storytelling and interactive content design, we proposed a platform to be a tool connecting story and interaction together.

### Storytelling platform

We introduced a Storytelling platform providing story organization and high-level abstraction to define object behaviors for generic interaction. Design and development of the story model should include interaction into a story. We need a conceptual framework to develop an interactive on-site VM and to solve these following objectives:

- The platform to design interactive VEs and to organize device connection dedicated to VM allowing users interact efficiently with the proposed knowledge.
- The platform to develop an adaptive interaction system that provides interaction techniques to activate and support users' interaction in VM.
- The platform should support self-evaluation of the content.

We introduced a new storyline by adding an interaction model adapted to storytelling model. Storytelling model created a theme in terms of VE where user interaction can be added. The Interaction model was used to determine the use of devices including interactive techniques. The details of the platform development were described as follows:

#### Storytelling model

The storytelling model was driven by the storyboard with subsequent elements to outline the story and to design scenarios with their situations. The storyboard was described with 3 components: entity, event and action. One entity was associated with a set of events trigger corresponding to actions on the scene. This structure allowed many choices of actions to describe situations of the entity. The action was the way to present an entity through the event condition. It was a static or dynamic story depending on the events. Animation, media and other options were the action components to control the story.

#### Interaction model

We defined a high-level abstraction for interaction model flexible for different devices. The same interaction tasks should be applied with the same result even using different devices. Model-Driven Engineering (MDE) was the conceptual models for abstract representation [16]. We developed the framework and applied MDE to define meta-models, transformations and mappings to address the problem of interaction plasticity and to support multiple devices [17]. The interaction tasks were considered to be selection, manipulation navigation and system control [18]. All devices were based on predefined interaction techniques (**Table 1**) which were set up as a device configuration. It needed to define the relationship between the device and the interaction techniques to allow changing devices. Interaction tasks in the interaction model were linked to interaction events in the storytelling model to implement events from high-level abstractions to low-level devices. The relationships between the story and the interaction techniques were independent.

**Implementation**

Our implementation described development process of an on-site VM installation, which used several devices for user interaction. A story in terms of VE was developed on the Storytelling platform connected to various interaction systems. Different interaction systems were set up with immersive devices from our laboratory. We set up 3 types of interaction systems with distinct user interface depending on the display device. The interactors for each system were designed to support interaction techniques implementation. Then the interaction techniques were defined as a method to interact with each system as shown in **Tables 1** and **Table 2**. The pre-defined interaction techniques allowed device changing later (**Figure 1**). Moreover, when we have a new system, we can redefine a new map and get another device behavior.

The 2D interaction system: this system was set up with a Powerwall and on a desktop device. The user interface used classical point and click and has menus on the top left. The standard interactor was a pointer.

The 3D interaction system: this system was set up on a stereoscopic projection wall with a Virtuose 6D haptic arm or an every Xbox controller. The user interface used 3D environment and has main menus on the top left. The standard interactor was a 3D pin avatar.

The CAVE interaction system: this system was set up on the MIHRIAD miniCAVE (a unique environment built in GSCOP laboratory with a desktop like allowing full 3D immersion sit down in front of the desktop) with a 3D wand. The user interface used 3D environment and has menus at the bottom space next to hands. The standard interactor was a 3D stick avatar which is aligned with the wand pointer.

**Table 1** Selection and manipulation tasks for each interaction system.

| Interaction | 2D | 3D | CAVE |
|---|---|---|---|
| **Selection** | Lclick | Lclick+ 3D ball collision | Lclick+ 3D wand collision |
| **Positioning** | Lclick+ dragging | Selection+ transition | Selection+ transition |
| **Rotating** | Lclick+ dragging | Selection+ rotation | Selection+ rotation |
| **Scaling** | Rclick+ dragging | Rclick+ 3D ball collision+ dragging | Rclick+ 3D wand collision+ dragging |

**Table 2** Navigation by travel tasks for each interaction system.

| Navigation | | | 2D | 3D | CAVE |
|---|---|---|---|---|---|
| Camera free | Translation | Forward Backward | Mouse FBscrolling | Lclick+ FBtranslation | Lclick+ FBtranslation |
| | | Left Right | Mclick+ LRdragging | Lclick+ LRtranslation | Lclick+ LRtranslation |
| | | Up Down | Mclick+ FBdragging | Lclick+ UDtranslation | Lclick+ UDtranslation |
| | Rotation | Pitch | Lclick+ FBdragging | Lclick+ UDrotation | Look up Look down |
| | | Yaw | Lclick+ LRdragging | Lclick+ LRrotation | Turn left Turn right |
| Walkthrough | Translation | Forward Backward | Keyboard FB buttons | Push and pull gripping tool | Lclick Rclick |
| | | Left Right | Keyboard LR buttons | LRtranslation of gripping tool | FBscrolling |
| | Rotation | Pitch | Mouse FBdragging | UDrotation of gripping tool | Look up Look down |
| | | Yaw | Mouse LRdragging | LRrotation of gripping tool | Turn left Turn right |
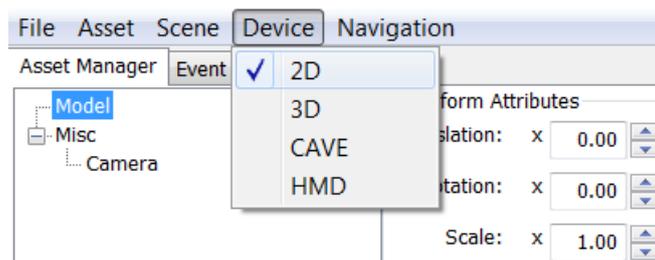
**Figure 1** The toolbar menus for interaction system changing.

**Development of a VM case study**

The Storytelling platform was proposed to create interactive content and enabled various device connections. Model transformation allowed device changing and interaction techniques without structure of the story or programming modification. We proposed a case study to investigate how different interaction systems and content affect learning and user behaviors. The interaction techniques were deployed within different interaction systems: 2D, 3D and CAVE. Device usage and performance were observed on each system, which related to the user behaviors. The evaluation of user engagement assessed the content used in experience with different interaction system. The interaction performance and capability on each type of content was also evaluated. This study was based on 4 hypotheses:

**H1 (Usability hypothesis):** participants have different performance to accomplish the tasks on different interaction systems.

**H2 (Needs of interaction hypothesis):** participants have different needs of interaction when using with different interaction systems.

**H3 (Learning hypothesis):** participants have different learning when interacting on different interaction systems.

**H4 (Holding power hypothesis):** the visit time depends on the interaction system.

The research question was about device usage and user engagement. Then the objective of this study was to compare the device performance of each interaction system and user behavior for different kinds of content. To answer the research question, we designed an experience using 3 types of content: a virtual tour, a semi-guided story and a non-guided story. Each content was tested with the 3 interaction systems: 2D, 3D and CAVE. This experience should support the evaluation of the 4 hypotheses H1 to H4 and details are in **Table 3**.

**Table 3** The evaluation of device usage and user engagement on comparison between each interaction system and the 3 types of content.

|  | **2D** | **3D** | **CAVE** |  |  |
|---|---|---|---|---|---|
| **Virtual tour** | 2D performance | 3D performance | CAVE performance | ⇨ | Device performance |
| **Semi-guided story** | Needs of 2D interaction | Needs of 3D interaction | Needs of CAVE interaction | ⇨ | Needs of interaction |
| **Non-guided story** | Holding power of 2D | Holding power of 3D | Holding power of CAVE | ⇨ | Holding power |
|  | ⇩ | ⇩ | ⇩ |  |  |
|  | User's behavior on 2D | User's behavior on 3D | User's behavior on CAVE |  |  |

**Virtual tour experience**

In the virtual tour, the visit was a mission where every interaction (selection, manipulation and navigation) was expected (**Figure 2**). The virtual tour experience was designed to investigate the performance of each interaction system following the usability criteria (H1). This scene was designed to test the performance of the device and interaction techniques. Users have the mission to navigate within the VE, which requires interaction techniques including selection, manipulation and navigation. The time spent on the mission and each device satisfaction was evaluated as the device performance.

**Semi-guided story experience**

In the semi-guided experience, the visitor's path was fixed, but visitor gaze was free and the visitor interacts with optional contents (**Figure 3**). They can also jump from one scene to another one. The semi-guided story experience investigates the impact of interaction system on visitor point of interest and need of interaction (H2). A semi-guided story was a linear story where users interact with the desired VE to access additional information. If the user has no interaction with the VE, the semi-guided story became a fully-guided story as a streaming video, but within a 3D immersive animation. Quantitative measures count the number of interactions of participants with each object. Each object in the scene has an attractiveness score defined by this number. Learning capacity (H3) was also assessed in this experiment by a post-questionnaire about the story comprehension after using each system. Two questions are asked with multiple choices. The summations of scores were used to evaluate learning performance with the interaction system. Furthermore, participants must complete a questionnaire about immersion perception and corresponding satisfaction.

**None-guided story experience**

The non-guided story experience was designed to validate the results from the virtual tour experience about the usability hypothesis (H1). Observation of the animation in the semi-guided story experience was quite far to the scene leading to the immersive scores. In this experience, user was inside the scene with a scale 1 rendering to increase the impact of immersion. Non-guided story was a non-linear story where behavior depends on the user interaction (**Figure 4**). In this experience, we examined the holding power (H4) of the system, but also how the interactive content attracts to user interest. The holding power was measured by the duration the visitor uses the system.



**Figure 2** The virtual tour experience on 3 interaction systems: 2D system, 3D system, and CAVE system from left to right.



**Figure 3** The semi-guided story experience on 3 interaction systems: 2D system, 3D system, and CAVE system from left to right.

**Figure 4** The non-guided experience on 2D single screen system, 2D full screen system, and CAVE system from left to right.

**Interaction system evaluation**

All 3 interaction systems 2D, 3D and CAVE were used with the same protocol. Before testing, participant was trained to use devices and to try interaction techniques. We divided the experience into 3 groups to avoid results bias due to modality order.

In the virtual tour experience, we explained the mission to participants. When the participant was aware then the time keeper started. Interactions were monitored to capture how long each device was used for navigation, manipulation and selection. At the end, each participant completed a questionnaire to assess the system usability.

In the semi-guided story experience, we introduced how to play/pause animation including how to jump to any frame on demand. Participant began the 1st scene with a specific interaction system. Then the story continued with the next interaction system until the last scene. Each interaction system took at least around 2 - 3 min to play the full animation. Participants had no limit of time to interact with the scene until they were satisfied. When the experience started, numbers of interactions with the scene were counted. After experience, participants answered the questions about their comprehension of the story.

In the non-guided story experience, the story was driven by user interaction. Participants needed to interact with various artifacts within the scene to obtain information. Hence, they were forced to use the interaction techniques. This experience had no expected time limit, and participants can stop at any time.

These experiences, involved 15 participants (11 males and 4 females) volunteer to take part in the study. The participants were aged from 23 to 42 (mean = 29.87). All of them had an experience with mouse and keyboard and joystick controller. Five of them had already an experience with the Powerwall and the stereoscopic display. Six of them had an experience with the CAVE system. Eight of them had no experience with any device. Each 5 participants started with the 2D system, the 3D system and the CAVE, respectively, and tested next system until they complete all systems.

**Interaction performance**

The virtual tour experience was used to see interaction performance. Since we have dependent samples of 3 interaction systems, we need to test parametric assumption first. The Shapiro-Wilk [19], W test was used for normality testing and the data respect to normal distribution then 1-way ANOVA was used to analyze the differences among group means in a sample.
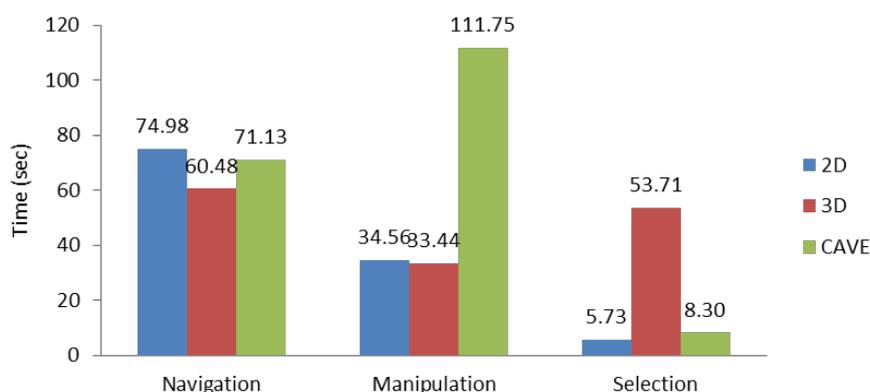


**Figure 5** Interaction time average in the virtual tour experience.

The time spent for the virtual tour experience showed in **Figure 5**. The navigation time for all 3 interaction systems were quite similar. While the CAVE system took more manipulation time than other systems and the 3D system lead to higher selection time. The 1-way ANOVA was used to confirm this observation. The result showed that the navigation time was not significantly different ($p = 0.137787 > 0.05$). The manipulation time was different with highly significance ($p = 5.38E-07 < 0.01$) because the CAVE system obviously had a higher average manipulation time. The selection time was also different with highly significance ($p = 1.84E-07 < 0.01$) because 3D system had a higher average selection time.

Tukey's post-hoc analysis [20] was used to check which system makes manipulation time and selection time different. The result confirmed that the difference of manipulation time was the CAVE system and the difference of selection time was the 3D system. Thus, H1 is significant: participant's performance depends on the interaction system.

We can conclude that a part of manipulation and selection problems on the CAVE system and the 3D system was about the design of interaction techniques. Because users felt that the CAVE system was not easy to manipulate and the 3D system was not easy for selection. Then we improved the design of interaction techniques and investigate another related factors in the none-guided story experience: the result was detailed in the section of interaction systems comparison in the end.

**Need of interaction**
The semi-guided story experience was used to check interaction need. The average amount of interactions that user perform on different interaction system is shown on **Figure 6**. Participants interacted on average 14.87 times in the 2D system, 3.67 times in the 3D system and 7.53 times in the CAVE system. The ANOVA result showed the highly significance difference of interactions among the 3 systems ($p = 0.000764 < 0.05$) and the Tukey's post-hoc analysis shows that the 2D system was different from others.
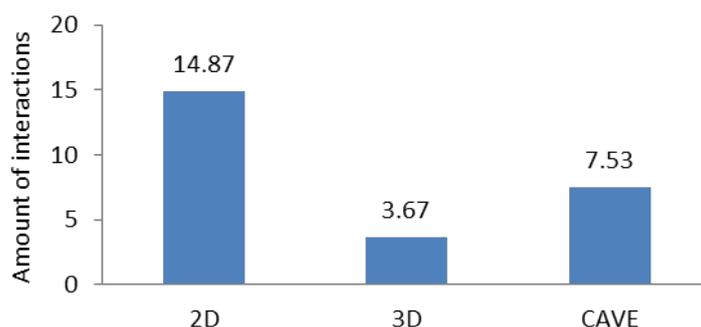


**Figure 6** Average of amount of interactions in the semi-guided story experience.

**Table 4** Usability of ease of use, immersion and satisfaction analysis of all experiences (* significant $p < 0.05$, ** highly significance $p < 0.01$)

| | Ease of use (max = 7) | Immersion (max = 7) | Satisfaction (max = 7) |
|---|---|---|---|
| 2D system | 6.39 | 5.33 | 6.41 |
| 3D system | 5.76 | 5 | 3.93 |
| CAVE system | 5.20 | 5.07 | 4.93 |
| p-value | 0.00026 | 0.2865 | 0.00053 |
| Significant | ** | | ** |

We considered results by grouping the questions about ease of use, satisfaction and immersion. Each question was used to collect average values for each system. In order to check the statistical data, normality testing was used again and the distribution was non-parametric then Friedman test [21] was

used. Ease of use and satisfaction were highly significant ($p = 0.00026 < 0.01$ and $p = 0.00053 < 0.01$, respectively) (**Table 4**). On the other hand, immersion was not significantly different providing the same result. Participants have more interactions when the interaction system was easy to use. Post-hoc analysis also showed that all systems were different about ease of use, while satisfaction was almost different, but 3D and CAVE systems were quite the same. Therefore, the ease of use and satisfaction were the keys of user perspective that made the interaction system different. We also accepted H2; participant have different needs of interaction when visiting with different interaction system.

### Learning efficiency

Ease of use and satisfaction were the significant key difference between the interaction systems. Then we examined what factors between ease of use, satisfaction and immersion impact user learning by analyzing the answers to the 2 comprehension questions of the semi-guided story. The scores revealed a relationship between the comprehensive questionnaire score and user perspective about ease of use, satisfaction and immersion on each system. The relationship between the scores and user perspective sorted from low to high value are shown in **Figure 7**.

The results of the regression analysis (**Table 5**) demonstrate that there was no correlation between the ease of use, satisfaction and immersion that impact the comprehension scores. This meant that user perspectives did not affect the understanding of the content. Moreover, when we compare the scores about the amount of interactions there is no significant relation. According to this result it implied that the comprehension scores are independent from the interaction system. We concluded that the experience was not significant respect to H3. Thus, participants did not learn differently when interacting on different interaction system within our experience.
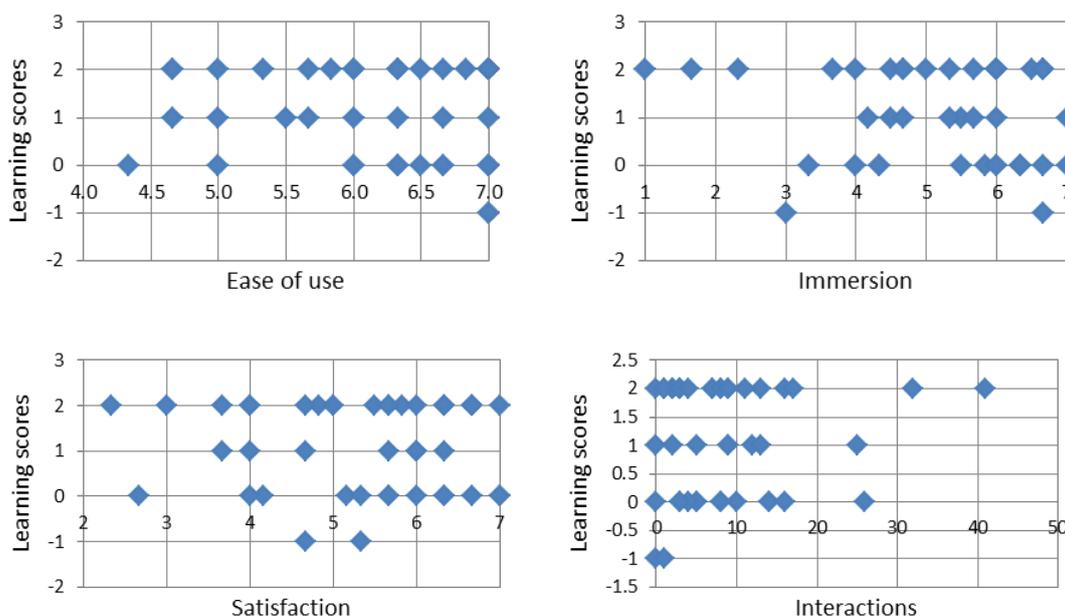


**Figure 7** Relation between user perspective and comprehension scores in the semi-guided story experience.

**Table 5** Regression analyses between user perspective and comprehension scores in the semi-guided story experience (* significant $p < 0.05$, ** highly significance $p < 0.01$)

| Regression statistics | Ease of use | Immersion | Satisfaction | Amount of interactions |
|---|---|---|---|---|
| Multiple R | 0.3488 | 0.3239 | 0.0018 | 0.2717 |
| MS | 2.4111 | 4.062 | 0.000206 | 150.9449 |
| F | 3.4619 | 2.9295 | 0.0001 | 1.9933 |
| p-value | 0.0746 | 0.0994 | 0.9928 | 0.1703 |
| Significant | | | | |

**Holding power**

The non-guided story experience was set up to validate the results from the virtual tour experience about the usability hypothesis (H1). Observation of the animation in the semi-guided story experience was quite far to the scene leading to the immersive scores. In this experience, user interacted inside the scene of scale 1 to increase the impact on immersion. The holding power was measured by the duration of the session.
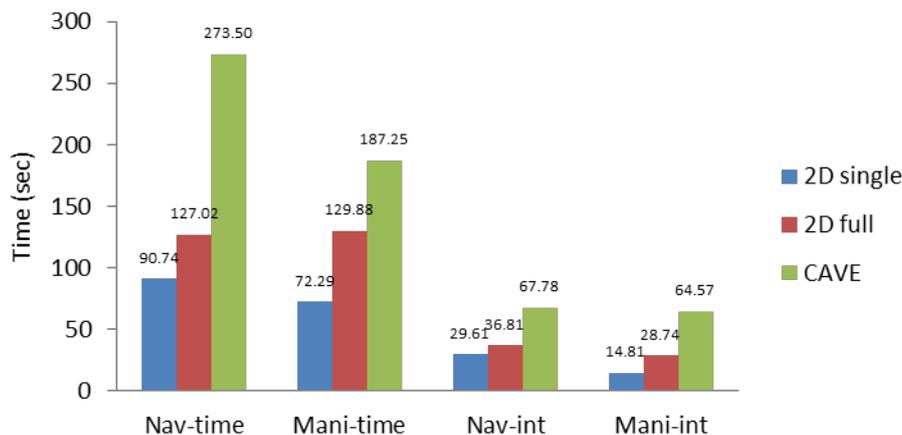


**Figure 8** Interaction time average in the non-guided story experience.

**Table 6** Interaction time analysis of the non-guided story experience (* significant $p < 0.05$, ** highly significance $p < 0.01$)

|  | Nav-time (s) | Mani-time (s) | Nav-int (s) | Nav-int (s) |
|---|---|---|---|---|
| 2D single screen | 90.74 | 72.29 | 29.61 | 14.81 |
| 2D full screen | 127.02 | 129.88 | 36.81 | 28.74 |
| CAVE system | 273.50 | 187.25 | 67.78 | 64.57 |
| p-value | 7.28E-05 | 0.00215 | 0.038254 | 1.34E-05 |
| Significant | ** | ** | * | ** |

The interaction times of the non-guided story experience (Nav-time = total navigation time, Mani-time = total manipulation time, Nav-int = interaction time of navigation, Mani-int = interaction time of manipulation) showed in **Figure 8**. The CAVE system seemed to provide more interesting experience. The navigation time, manipulation time, interaction of navigation time, and interaction of manipulation time were compared in the non-guided story experience. The result showed that the interaction time of the CAVE system was longer than the 2D full screen system and the 2D single screen system, respectively.

The 1-way ANOVA was used to test the null hypothesis that the means of several interaction times are all equal. The results confirmed that all interaction times of each system were significantly different. These systems affect user behaviors for navigation time and manipulation time. End users spent more time in the CAVE than other systems. Tukey's post-hoc analysis was used again and confirms that CAVE system was different from others. Thus, we accepted H4, participants had more interaction time when the system was more immersive. The CAVE appear to provide higher holding power.

The development of the semi-guided story experience proposed interaction with objects into the scene following the story and information to users. However, in the actual usage, the user may have a different interaction from the design. We should capture the user behavior, how often do users interact with each object within the designed scene? If the design did not meet the user needs, VM designer should know which objects or locations should be updated in order to meet the user requirement.

The storytelling platform was designed to support this idea. We kept all interaction data which can make a report to the developer when user finished using the system. The report will save the amount of

interactions with the scene and where is the user point of interest. Virtual museum developers can use this report to improve attraction and interaction respect to user requirements.

The interaction design within the scene compared to the actual usage showed in **Figure 9**. It was found that some object interactions were quite different. Within the large dashed rectangle, we proposed large number of interactions, but the user interacts rather less. May be the arrangement was not interesting or the story in this part did not appeal to the user. In the small dashed rectangle, we did not propose any interaction, but many users expect more informations by trying to interact on objects. From the user feedback, they were interested in the far mountain and river of the global environment and want to know the name and information about these objects. This report addressed the needs of users and can be used to improve the design of interactions for user interesting. VR becomes a user centered design environment for VM.



**Figure 9** Object interactions from actual usage compares with the interaction design of the semi-guided story experience.

From previous results, we accept H2 and cannot consider H3. It also affected the design of VE. In order to let users have more participations, interaction system should be easy to use. Although, it does not affect to story comprehension, but the design of VE affects user attention.

### Interaction systems comparison

The 2D Powerwall system has a large display that is ideal for multi-user applications. Content should focus on interacting with the system by selection. Because of its huge screen and the wide range of view provides immersion. Despite the huge wide screen, the 2-dimensional display makes selection easy. However, with 2-dimensional display, users lack depth perception, resulting in immersion loss.

The 3D stereoscopic system has a large 3-dimensional projection that can be viewed by multiple users at the same time with shutter glass, but the visibility of each user may be slightly different from various positions. The advantage is that VE is visualized in 3D and user perceives depth, which increases immersion. However, it makes selection and manipulation more difficult than usual 2D displays. We found that users spent more time in selection and manipulation in 3D system because depth perception is added. It is not easy to move the selector in a 3D scene with a joystick controller, while tracking device should be better to move a selector in 3D for selection and manipulation. In contrast, navigation time with joystick controller is not different from the 2D system, which means the interaction design is appropriate.

The CAVE system uses multiple immersive 3-dimensional displays. Wider volume and viewing make it possible to perceive fully immersion VE, but it cannot be used by multiple users simultaneously due to individual tracking system. The content should be a scale 1 in 3D then users can get direct interaction with objects, such as in 1st person mode navigation. The results show that user perception about immersion is not different when presenting VE from a far distance. By the way, using VE close to a user, immersion is significantly different. Therefore, the CAVE system provides a better immersion at the condition to be in 1st person mode at scale 1 very close to objects. Without these conditions a 2D system provided a better experience. Another advantage of the CAVE system is user attraction or holding power. We found that users spent most of their time interacting within the CAVE system. This is consistent with the results in virtual tour experience. Users spent more interacting time. It is not due to poor performance,

but the system is attractive for users and they play a longer time than usual. This is good for content that requires user attention for a long time. However, high immersion values are associated with lower satisfaction because users are more uncomfortable when using the CAVE system too long.

**Implementation of adaptive interaction system**

In this research, we set up devices for our experience with only 3 systems: the 2D system, the 3D system, and the CAVE. There may be new devices coming in the future such as Head Mounted Display (HMD), HoloLens, etc. Our platform was designed with adaptive interaction system while the story and interaction technique implementation of selection, manipulation and navigation remains the same and can be compared. In the future, new VR devices are coming and we face to the challenge of VM study in terms of user interaction. Using HMD devices in the learning process [22,23] is better than using video and also more satisfying. In order to compare new devices and the previous devices with the same story and interaction techniques. We need the adaptive interaction system to support devices and interaction techniques organization related to the story in VM. Our framework provides the necessary tools required to prove this idea. This is very useful for research about VM development and the development of interactive media to assess learning and user engagement. In the VM research is different from VR research because it is related to the content or story. The comparison of VR devices are based on device performance and the story is not necessary [24,25].

## Conclusions

We assessed device performance, usability of interaction, user satisfaction and immersion with VM exhibition. The results of this study contributed to design the content for interactive on-site installation VM application. This paper achieved contributions to understand the development of VM applications to better immerse museum visitors into VM. A Storytelling platform to design interactive content with various devices was proposed. This feature allowed developers to study user behavior with applications through interaction systems using different interaction techniques. We added functionality for reporting user interaction to the platform, allowing us to capture user data during interaction with the system. The platform report elapsed times of each user the navigation time, the manipulation time and the selection time. It supported developers to investigate mistakes in the actual usage to have better interaction techniques in a new development loop. This platform was designed to monitor not only the time of interaction, but also the amount of interactions on each object in the scene. The report showed how many times users interact with each object in the scene, which allowed developers know user behavior with the current exhibition. This information can be used to improve the interactive content of VM development to meet the needs of users. We reached a kind of user centered VM design.

In the development of the Storytelling platform, we highlighted that when creating applications using different devices the system has different performance. The user interacts with each device differently, but content learning of each device is not different because the user learning mainly depends on the content. We can enhance the interest of the content through the selection of appropriate devices and interaction techniques. However, most VM applications have features adapted to multi-user applications. In the future, Storytelling platform should be developed to support multi-user and inter-user interaction. This concept will allow us to study the behavior between users to enhance the learning experience of the VM in the future.

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