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Virtual Museums as Learning Agents

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Abstract: Virtual solutions for exhibiting museum collections are no longer a novelty, as such experiences already exist in the world, but the remote use of museum collections for learning purposes has so far not been widely used in the educational environment. This article analyzes virtual museum applications by evaluating them from a learning perspective, including 25 criteria in the evaluation rubric divided into three groups: (i) Technical performance; (ii) information architecture; and (iii) educational value. This will enable educators to select the most appropriate material for their specific learning purpose and to plan the most appropriate learning strategies by organizing training sessions to acquire knowledge that can be enhanced by museum information and teaching students digital skills in evaluating information available in the digital environment, analyzing its pros and cons to teach them how to develop new innovative solutions. The research is carried out from a phenomenological perspective; to be more precise, virtual museums are analyzed using the principles of transcendental design and a hermeneutic design is used to interpret the resulting data. A total of 36 applications of virtual museums were analyzed, whereupon the results were compiled using static data analysis software, while 13 applications were used for the hermeneutic data analysis. The results suggest that the strength of virtual museums is in information architecture, but less attention is paid to the educational value of the material, which points to the need to change the principles of virtual museum design and emphasizes the role of teachers in using virtual museums as learning agents.

Keywords: virtual museums; technical performance; information architecture; educational value; learning agent; learning perspective; evaluation rubric

1. Introduction

Different virtual solutions allow diversification in access to information, learning, and getting to places you would not otherwise be able to go [1]. Virtual solutions are becoming more accessible, attractive, and immersive and incorporate an element of the avatar that is directly related to parts of the body and provides a better understanding of the reality seen [2], and the individual has the ability to interact with virtual environment artefacts, build their own understanding, develop their cognitive processes, and foster their creativity and the development of new innovation. The developed technical solutions' graphical design, artefact aesthetics, information architecture, interoperability and also the possibility of their usage in an educational setting are analyzed.

The research is based on the idea that virtual solutions and smart devices that complement each other can serve as learning agents, but in order to be fully utilized in the educational environment they need to be evaluated, and the aim of this study is to evaluate virtual museums from a phenomenological perspective to understand their potential for educational purposes. In short, the study seeks to answer the following research question: What is the potential of virtual museums from a learning perspective, and can they be used as learning agents? In order to achieve the aim and to find the answer to the research question, the objectives of the research are:

1. Analyses of mobile virtual museum applications with previously developed and approbated evaluation rubric [3], which is updated for the needs of this research from three perspectives that synergistically complement each other: (i) Technical performance; (ii) information architecture; and (iii) educational value, using the principles of transcendental design
2. Quantitative analyses of the data collected to find out the best apps from an educational perspective and qualitative data analyses by using hermeneutic design to interpret the resulting data.

- The author used the developed and validated evaluation rubric [3], which was updated to add more structure and a few more criteria (see Appendix A).
- Applications were searched for on the App Store using the keywords "virtual museums", and 56 virtual museum applications were found to be available at the time of the research. After their initial evaluation, 36 applications were evaluated in accordance with the developed evaluation rubric and 13 apps were chosen for in-depth analyses.
- The obtained results were analyzed from a learning perspective, using quantitative and qualitative data analysis methods.

This paper is structured as follows: Section 2 analyzes recent literature on museums as a learning agent from a learning perspective and the role of information architecture in the development of digital materials. In Section 3, an explanation of the research design and methods used is given. In Section 4, the research results and a discussion of these results are presented, Section 5 is devoted to the discussion and in Section 6 conclusions based on the data collected during the research are drawn.

2. Virtual Museums as Learning Agents

2.1. Learning in Museums

Along with the development of virtual solutions in different directions, such as:

i) Where virtual reality (VR) experiences can be enjoyed in specially created VR theatres using the necessary hardware, software headsets, multi-projected environments, and physical environments to produce real-life images, sounds, and other sensations [4] that are transferred to the VR user through virtual simulation and the transfer of this experience is mediated through a mobile device, tablet, console or computer [5];
ii) Where visual experiences can be complemented by a variety of immersive experiences (haptic, smell, temperature, etc.);
iii) Where the VR environment is mixed with the real environment—it is also possible to extend their range of use.

As a result, the use of virtual solutions is expanding, but it is also necessary to broaden the scope of research to include the use of these different opportunities in education. For example, Garzón and Acevedo (2019), in their literature review on the use of augmented reality (AR) in education, concluded that there is only one article evaluating AR from the perspective of educational sciences [6]. Virtual solution capabilities also need to be evaluated before they can be used as a tool for scaffold learning and the development of metacognition [7,8], rather than only to entertain and fascinate people.

For museums, virtual solutions are tools to help provide information about the museum that visitors may need, but this is not currently the focus of research. In the following, virtual museums will be analyzed from a perspective where they can serve as a tool to overcome the various constraints faced by museums themselves, such as the need for rooms to display all the artefacts available to them, the need to attract visitors, and the desire of visitors to interact with museum artefacts as much as possible. Virtual museums can serve as a tool for learning by entertainment, where learning takes place through active exploration, collaborating with virtual agents [9], or as an interaction with a virtual narrator that is humanlike and capable of communicating, while using the museum. The use of different narrators is recommended to give the user of a virtual solution a sense of presence [10] where it is possible to interact with artefacts (smart objects), which are technically simple embedded systems equipped with sensors, actuators, and networking capabilities [11]. The Ars Electronica Center for Electronic Art in Linz, Austria, which houses a CAVE-projection VR in which users stand between six walls of a room-sized cube, is considered to be the first museum to use virtual solutions in its exhibitions [12].

Given that VR experiences with immersion effects are expensive to produce and require human presence to experience this immersion, museums are increasingly using a variety of other virtual solutions that connect to museums using personal smart devices and combine virtual-created artefacts and real environment scenes:

a. To interest society in museum collections because virtual solutions allow people to explore other dimensions of information and one of the challenges facing museums is fighting for visitors' interest;
b. To display artefacts and situations that would otherwise not have been displayed, such as artefacts that no longer exist or historical situations that are no longer experienced;
c. To preserve and allow access to a variety of exhibitions that an individual can visit virtually without time and national boundaries, as exhibitions are variable, but preserving them virtually can preserve contemporary history, thus, contributing to the sustainability of cultural values;
d. To contribute to the development of an inclusive society, as access to museum experiences in this way is more accessible, both in terms of physical access (such as people with reduced mobility) and in terms of cost (for example, getting to a museum in Paris can be quite an expensive adventure).

Nowadays, museums have the task of not only storing and preserving historical values, but also of using them for learning purposes [13]. From the perspective of educational sciences, learning in museums is one form of situated learning [14,15] where access to a variety of knowledge is possible, providing learning opportunities that enhance individuals' interest in knowledge accumulated in museums, interacting with virtual artefacts, and enabling them to interact with substance and concreteness with the museum's intangible artefacts [16]. Such learning can also support culturally responsive teaching [17], and there are initiatives taken to blend learning in the museum and use of technologies. For example, MyArtSpace project [18]. However, despite the advantages of this type of learning, there are some limitations, since situated learning also involves active interacting with artefacts in a given environment, but these artefacts must be preserved for the future, which creates a contradiction in their practical use [3]. Thus, there is a need to look for solutions to engage students, to promote active learning, and to provide it with the available technological affordances. Virtual solutions and their use for educational purposes have great potential as they can be used as learning agents [19], and agents for preserving cultural values. Their use can also address the conflict between the principles of active learning used in a situated learning environment and the need to preserve historical values. State-of-the-art virtual solutions make it possible to create virtual museums and VR/AR experiences, as well as to provide people with a variety of information to enhance the museum's message and empower knowledge and awareness [20]. The important place in learning takes different kind of mobile learning, which is platform-independent, utilizes web-based platforms and incorporate in learning mobile applications to support learning anywhere and anytime, to move beyond static content delivery [21]. Educational researchers use different terms to name the learning through mobile devices, but the most appropriate term for the learning in virtual museums which tends to blur the borders between real space and virtual space seems 'authentic mobile learning' introduced by Burden and Kearney [22]. Thus, virtual museums can be considered as learning agents for upward learning curves, as such solutions can help broaden the spectrum of collaboration with digital materiality and help visualize and spatialize abstract concepts [23]. There are studies that have found that using VR solutions stimulates learning motivation because it makes learning more interactive [24], and makes it possible to get feedback in the learning process itself if the information is properly constructed [25,26], which highlights the importance of information architecture in a digital learning environment. Their potential is also based on the idea that technical systems can also be agents from a psychological, sociological and learning perspective [27,28]. Virtual museums have specific characteristics that support the idea that they can serve as learning agents because:

i) It is possible to augment analogue reality with digital information;
ii) Integration takes place in real time and in a coordinated way;
iii) They facilitate combining different resources: Text, websites, video, audio and 3D;
iv) They are interactive; and
v) The involvement of the individual is necessary for the creation of the content [29].

The use of technological solutions as agents in the learning process helps students to analyze, assimilate, contextualize and synthesize their knowledge, thereby providing new levels of thinking and also, positively influencing students' learning motivation by developing a deeper understanding of specific knowledge [30]. In this way, virtual museums are perceived as learning agents that offer access to information concentrated in museums and restricted artefacts within them and facilitate situational learning [15] or authentic mobile learning [22]. In such way, individuals can use their smart devices to connect to this knowledge, where learning, to a certain extent, can be organized in a specific environment and under certain circumstances that would not be possible without the use of virtual solutions.

2.2. Smart Learning Environments

There are articles in the research literature that justify students learning differently nowadays [31]; however, the use of virtual museums as learning agents requires the teachers' seamless presence to provide students with the appropriate learning experience, thereby becoming a knowledge transmitter, and thus, forming a multi-agent network as anything can be considered as a learning agent. The role of the teacher in this network of agents is still very important [32], because the virtual solutions available today cannot completely replace the human pedagogical element; as Garzón and Acevedo's study concluded [6], such solutions have medium learning gains and are difficult to use because teachers do not have the appropriate pedagogical, content and technological competences [33]. There are also studies that conclude that students are not yet ready to learn using such solutions [29,34]. This demonstrates the need to enhance the baggage of smart pedagogic solutions so that various technological affordances, including virtual museums, are used as learning agents, as these solutions not only solve access problems, but are considered to be used for scaffolding learning in authentic mobile learning space. They are involved in the process of information perception, which facilitates the memorization of information, and thus, the construction of certain knowledge [35], and strengthen learning and bring joy to learning itself through experiencing physical phenomena in a mixed reality (MR) environment [36].

Learning using a variety of technological solutions was defined by Spector as smart learning [37], though this type of learning is sometimes defined under the umbrella term "digital learning" [38,39], while other authors choose the term "digital agency" to describe the whole spectrum of the digital environment. The pedagogical principles to be considered, when organizing a technology-enhanced learning process are called smart pedagogical principles [40], and when planning and organizing technology-enhanced learning these should be considered to have not only fascination effects, but also learning outcomes.

Another factor that is important when thinking about using virtual museums for learning is information architecture, which can support the learning flow; conversely, the information flow can be so complicated that it is inconsistent with the perceptions of the user that its only outcome is a fascination with the technological affordances, not its use as a learning agent. At present, the Internet and the information available there is not perceived as a "different and separated world" or domain, but rather as part of a larger mechanism in which the consumption and retrieval of information take place in different contexts using multiple physical and physical-digital overlapping and interacting devices [41]. The information architecture has moved away from a single artefact to an interconnected network, some parts of which may not even be online or even digital at all, and one solution is the Internet of Things (IoT), which is developing broader information and semantic environment [42]. Virtual museums that can be used with personal smart devices can be considered as one example of IoT that can serve as learning agents.

Lacerda, Lima-Marques and Resmini [43], with reference to Resmini and Lacerda [44], and Benyon and Resmini [45], define information architecture units as "actor-driven, information-based, semantic constructs connecting individual touchpoints into (a) transient architecture", assuming that actors (virtual museum users) use agents (virtual museums) to cross the boundaries of the information space that connect the contact points to achieve the desired position in the future, which from the educational perspective means scaffold learning outcomes and metacognition. This information space brings together previously unrelated information spaces in various ecosystems that participate in the wider infosphere [46], combining individuals, artefacts, places and events, and act as learning agents. Lacerda, Lima-Marques and Resmini define 16 information architecture principles that can be divided into three categories, which are: (i) Architectural principles that take into account the perspective of information space and artefacts; (ii) human principles that take into account the subjective perspective of subject/object interaction; and (iii) systemic principles that take into account the perspective between artefacts, actors and systems in information ecosystems [43].

Fowler emphasizes three stages of learning through VR that can also be taken into account for virtual museums:

i) Conceptualization (where the learner learns and interprets different facts, concepts and theories and receives information);
ii) Construction (where the learner evaluates facts and concepts, applies knowledge in an interactive way, solves or analyzes problems, tests the use of concepts in new situations, and observes real-life experiences by building on his/her own knowledge of the experience);
iii) Discussion (the learner discusses what he/she has learned and his/her own learning) [47].

As can be seen, getting information is indicated right from the first stages of learning so that the individual can then construct his or her knowledge and apply it in new contexts. If the flow of information has been inadequate, it also jeopardizes the learner's advancement to the next stages. It proves that virtual museums can be used as learning agents if the information provided by the agent is consistent, constructive and aesthetically and pedagogically correct, which requires that the information architecture is in synergy with smart pedagogies, where visual, audial and textual information (and, in some specific cases, immersive information) should be taken into account. When an image (otherwise perceived as an item of information) is analyzed, cognitive processes are activated, and this facilitates metacognitive development [7]. The accurate mapping of data with the visualizations used is critical, as disregarding information architecture principles can result in the loss of relevant information or in exceeding the allowable amount of irrelevant information [48], and this has an impact on the learning process as it can lead to cognitive overload. The virtual museum application should be simple, usable and aesthetically pleasing as the app needs to work efficiently and not break down during use [44].

This article focuses on the evaluation of virtual museums from an educational perspective, because despite the widespread use of virtual solutions, there is still a lack of research focusing on the utility, challenges, efficiency and parameters of their use [48]. There are studies showing that MR (which is often used as an umbrella term for various VR solutions, including AR solutions) has a positive effect on student motivation and willingness to engage in learning activities [6,49,50]. This educational evaluation of various virtual museums is important for a number of reasons:

i) To explore the potential of using these experiences from a subject-oriented perspective and from the perspective of motivation and [50] cognition sensory development, emotional development and/or the development of specific skills [51,52]. In general, this could be defined as the learning outcome perspective. For example, learning about the events of a historical period, getting into that environment, or accessing places that would not otherwise be available.

ii) To identify gaps in the supply of these experiences and to fill them with other pedagogical activities. For example, evaluating whether a particular virtual museum includes an aspect of assessing learning outcomes or whether it is appropriate for students with different learning needs.

iii) To help students navigate through a range of experiences and use these virtual museums as learning agents. For example, if students have a desire to learn about the architecture of a historical period or if students need to learn how to deal with hazardous substances, etc. then virtual solutions can provide them with such opportunities.

iv) To help teachers scaffold learning to enable the students to become skilled users of technology and creators of new technological solutions. For example, if a teacher is working with students to evaluate a museum's technology solution and look for ways to improve it, such as improving the layout of artefacts, improving visual graphics, changing the information flow, and so on.

3. Research Design Methodology

The research is carried out from a phenomenological perspective; to be more precise, virtual museums are analyzed using the principles of transcendental design and a hermeneutic design is used to interpret the resulting data, which deviates from the descriptive nature with which the phenomenological approach is most often associated [53,54]. No individual persons are involved in the research, nor are the personal data of individuals used.

An evaluation of 36 virtual museums was conducted to conceptualize the existing and potential capabilities of virtual museums as learning agents (see the full list of evaluated experiences in Appendix B), using the researcher's personal smart devices (an iPhone and iPad) to connect to them. Virtual museums were selected by entering the keywords "virtual museum" in the App Store, and their free apps were chosen based on the idea that virtual museum visits are accessible to anyone with a smart device and an internet connection and that no other resources are required. No other selection criteria were applied according to the country of application, museum theme, or other formal criteria. A total of 56 applications were selected, but 14 of them were intended solely to inform museum visitors about the museum's opening hours, ticket prices, access, exhibitions, and other practical information. Another four experiences were excluded from the evaluation because their suggested language was unknown to the author (French, Polish, and Chinese). Two more apps were excluded because, despite being listed as free, there was a charge for attending each exhibition and space. After an in-depth evaluation of all criteria, 36 virtual museum applications were selected for analysis.

An evaluation rubric was used to ensure the objectivity of the data analyzed, but there was still some subjectivity as the researcher's perspective was used to evaluate particular criteria [55]. During the evaluation of the experiences, the educational perspective was the most dominant one as the researcher represents the field of education, and during the evaluation, the students' perspective was kept in mind by using the researcher's personal experience of working with students of different age groups. As the basic structure of the evaluation rubric had already been developed in the previous research phase [3], with the result that only the order of the criteria needed to be changed and five new criteria added, the initial phase of the study took a short period of time. The selected applications were then evaluated, and the obtained results were quantitatively and qualitatively evaluated, according to the comments made during the evaluation of each virtual museum application. The selected virtual museums were analyzed between September 2019 and January 2020. The evaluation rubric was used to evaluate the virtual museums and contained 25 criteria divided into three groups: (i) Technical performance (11 criteria); (ii) information architecture (5 criteria); and (iii) educational value (8 criteria), as well as one criterion for specifying the age groups for which the assessed virtual museum may be eligible. The boundaries of these groups are not strictly separated (see Figure 1), because all factors interact and influence information perception processes, thus, affecting the ability to store information in long-term memory, analyze it and synthesize new knowledge concepts, which is the primary goal of the educational process. Assuming the virtual museums are used as learning agents, they were rated in accordance with the developed evaluation rubric, which was developed inductively based on extensive literature analysis, the personal experience of the author and a pre-approved evaluation tool [3] based on the principles of an analytical rubric [55]. Each of the criteria in the rubric is evaluated on three levels, each of which has its own description (see Appendix A). After evaluating each of the criteria, the possibility to add comments describing the specific criterion and the chosen rating was provided. During the quantitative analyses of the results, the levels were indicated by numbers where 1 indicated the lowest level, 2 indicated the medium level, and 3 indicated the highest level of the criterion. The structure of the evaluation tool was adapted from the work of Stevens and Levi [56].

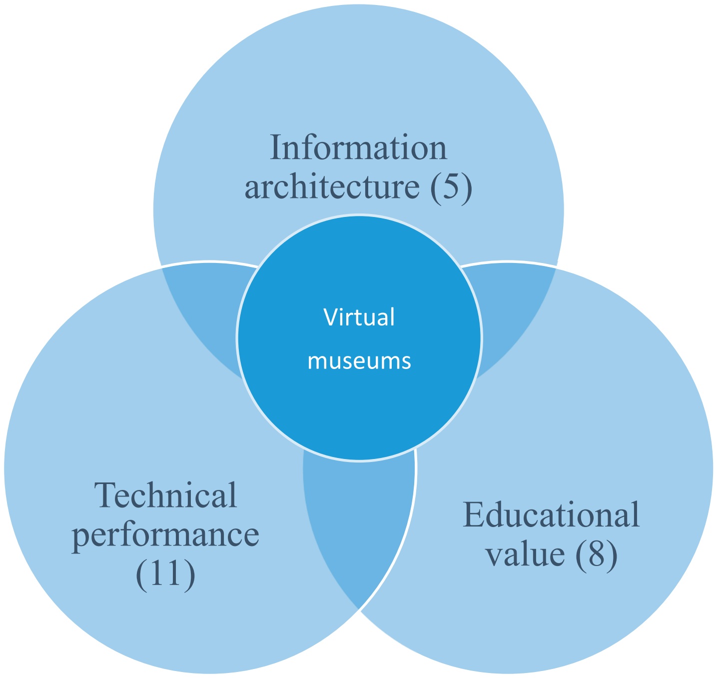

Figure 1. Structure for the evaluation of virtual museums.

4. Research Results and Analyses

The obtained quantitative results were analyzed using Excel, where the mean values for each group of criteria and for each virtual museum application were calculated separately. Most virtual museums are dedicated to the arts (paintings, sculptures, architecture); the next largest group is history museums (state history, history of war, history of a factory, inventions of Tesla). There were separate museums for some objects (Nefertiti, Tank Tour), one museum for Dineladi cave and one museum on the Solar System.

4.1. Quantitative Results of Analyses

The quantitative data analysis, summarizing the averages of all 36 virtual museums analyzed (see Figure 2), shows that the highest scores are in the criteria that characterize information architecture, and there are five museums (*Civilizations, UMA/Universal Museum of Art, Houghton Revisited, Nikola Tesla Experience, Tank Tour*) with the highest rating (3) in this category. For technical performance criteria, the highest mean was 2.73, which was for *Civilizations,* followed with a mean of 2.55 by *Pompeii* and *Houghton Revisited.* In contrast, for educational value criteria, the highest mean was 2.57 for *Civilizations,* which was followed by *Daily Art* with a mean of 2.29 and *Tank Tour* with 2.14. These indicators are summarized for all evaluation criteria, where some of the technical criteria received very low ratings—e.g., *Possibility to interact with the narrator* (mean 1.06) and *Possibilities for people with special* *needs* (mean 1.14)—thus, reducing the rating of the technical criteria group as a whole, but it is clear that the lower endpoints are the educational value criteria for using these applications as learning agents.

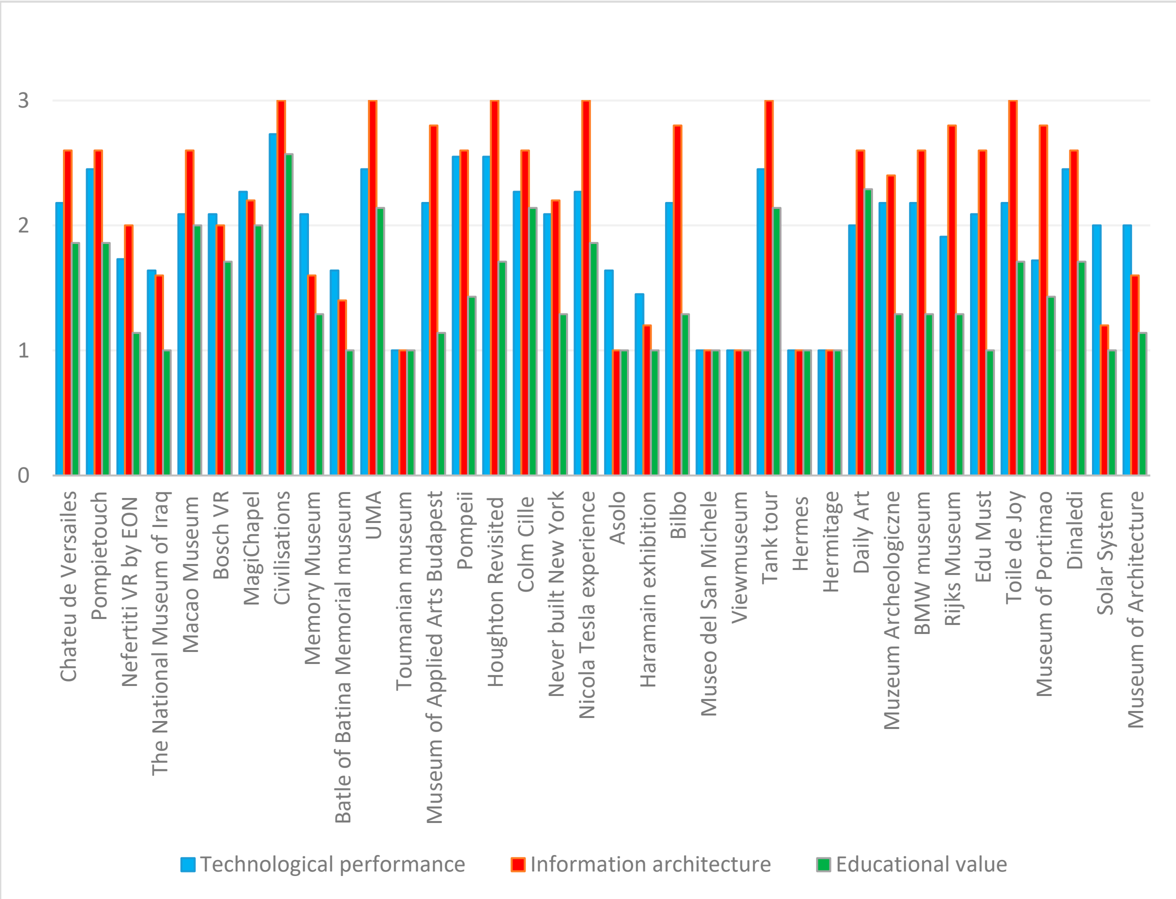

Figure 2. Evaluation results_all virtual museums (mean). (Abreviation EON is company title EON Reality Inc. – and UMA – Universal Museum of Arts).

It can also be seen that there are five museums that received the lowest possible point (1) for each of the criteria, and as such these museums cannot be analyzed because of their low technical performance and low educational value.

The mean scores of all the evaluation criteria were further analyzed to determine which the highest and lowest values were across all the analyzed virtual museums (see Figure 3). Within the group of technical performance criteria, the highest results are for *Use of the material* (mean 2.58) and *The graphics of the material* (mean 2.56), while the lowest rates are for *Possibility to interact with the narrator* (mean 1.06) and *Possibilities for people with special needs* (mean 1.14). In the information architecture group, the highest scores are for *The sequence of information flow* (mean 2.31) and *Structure of the information provided* (mean 2.25), and the lowest scores are for *Information about the historical period of the artefact* (mean 2.03), and *Information provided during the use of the material* (mean 2.11). For the group of criteria that describe the educational value, the highest scores are for *Additional information is given in audial form* (mean 1.72) and *Connectivity with other information* (mean 1.72), and the lowest for *Elements of gamification* (mean 1.14) and *Knowledge test* (mean 1.17).

4.1.1. Technical Performance and Information Architecture

In the following, applications of virtual museums whose mean were higher than 2 points for technical performance and information architecture criteria were selected, totaling 24 applications (see Figure 4). It can be seen that the mean values for most applications are higher in information architecture criteria, and these technological features can be used as a supporting tool to ensure learning via virtual museums.

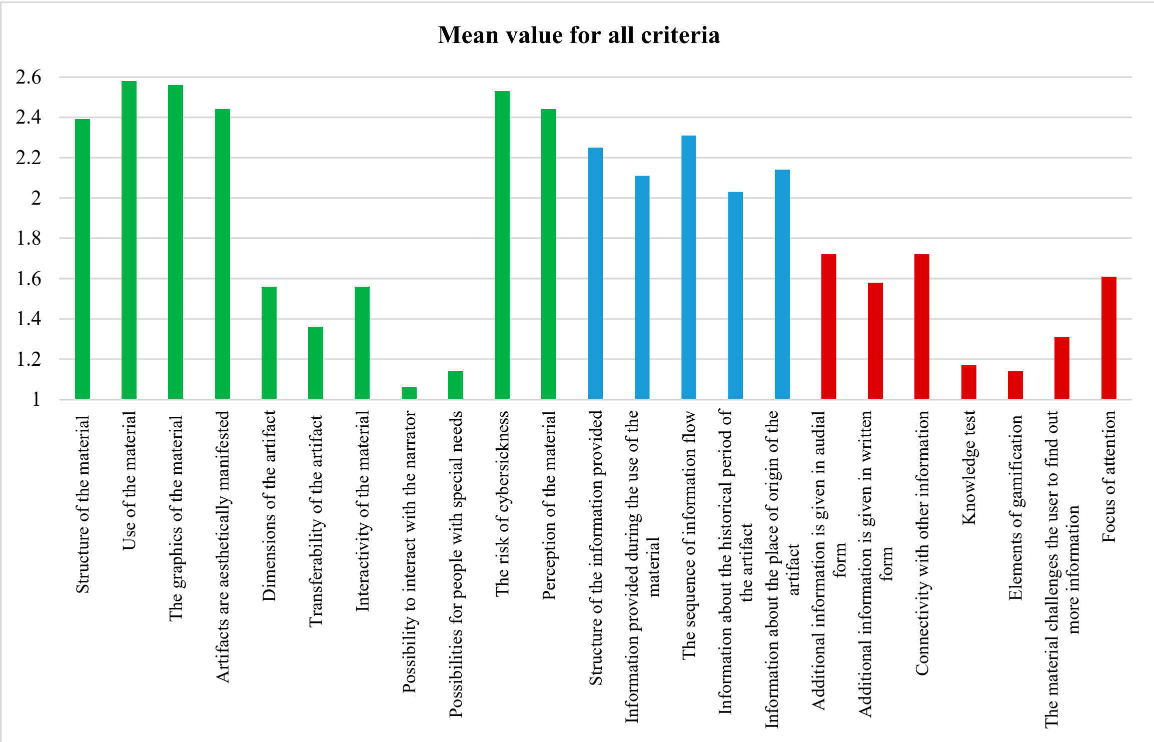

Figure 3. Mean value for all criteria (green: Technical performance—average mean 1.96; blue: Information architecture—average mean 2.17; red: Educational value—average mean 1.46).

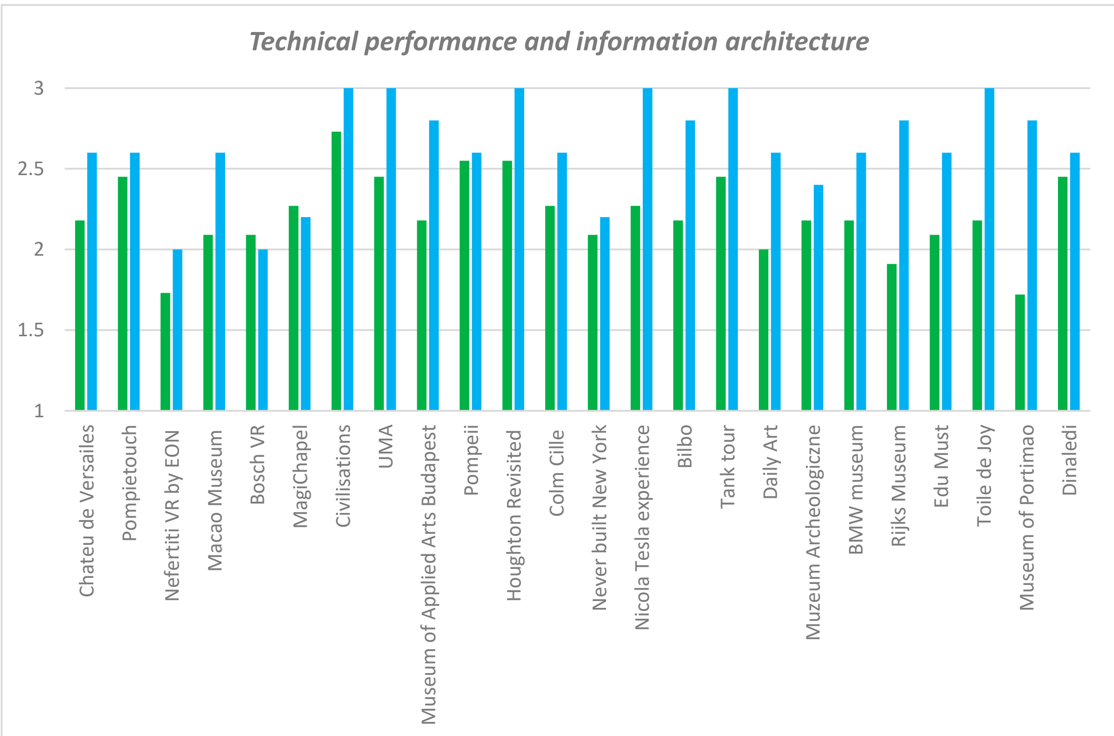

Figure 4. Technical performance and information architecture (green: Technical performance; blue: Information architecture).

4.1.2. Educational Value

Analyzing the educational value criteria, it can be concluded that the criterion *It is possible to organize group activities* was not technically available in any of the virtual museums, and therefore this criterion is excluded from further analysis. An in-depth analysis of virtual museum applications was performed for those apps where the mean score of the criteria exceeds 2 points, totaling 13 applications (see Figure 5).

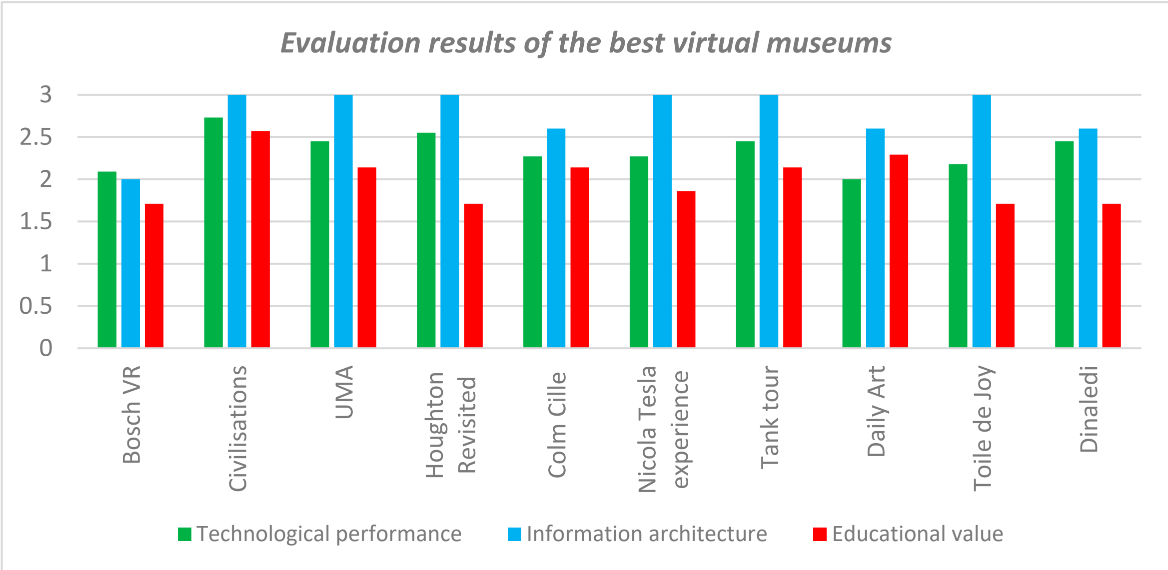

Figure 5. Evaluation results of the best virtual museums (mean).

Two museums with a mean score of more than 2 are not included in the analysis below, however: The *Macao Museum*, because all the information that could be read is only available in Chinese, and the *Chateau de Versailles*, excluded because a lot of the information is only in French.

Taken together, the results indicate that the scores for all criteria groups are different, and the mean educational value criteria score is higher than the technical performance score for only one of the virtual museum applications (*Daily Art*). This confirms the idea that virtual museum applications can only be used for educational purposes if a person is motivated to seek additional information or already has information that may help them to understand the information provided in the application. Otherwise, teachers' seamless participation is needed.

4.2. Hermeneutic Data Analysis

The following is a hermeneutic analysis of comments made during the evaluation of virtual museum applications. This section analyzes only the 13 applications which were selected for deeper analyses in the previous stage because of the mean scores (see Figure 5) that were included in the in-depth analysis in the tables below: Table 1 summarizes the analysis of technical criteria, Table 2 summarizes the information architecture criteria analysis, and Table 3 includes information on the analysis of educational value criteria. The tables are divided into three columns: The first lists the criteria, the second shows the average mean value for each criterion, and the third shows the results of the hermeneutic analysis.

Although some of the applications were excluded from the in-depth analysis, a positive example would certainly be *Petite Galerie*, in which it is possible to obtain information for people with visual or hearing impairments when the user first opens the app, the graphics offer the option of an alternative method of information provision for people with visual/hearing impairments. Unfortunately, we could not investigate this further because the app was only available in French.

Table 1. Evaluation of technical solutions.

Technical Solutions		
Criteria	**Avg. Mean**	**Comments**
Structure of the material	2.39	Most of the virtual museums' material has a clear structure. For most of the museums, two to eight languages are available
Use of the material	2.58	It is easy to understand how to use the material; in some cases, there is an introduction to the material and an explanation of how to use it. Some of the materials lack instructions but the user can understand the principles because the material is developed with intuitive logic, but there are also cases where the logic of the material is unclear (*Colm Cille*). There are also cases where there is no option to go back to the previous stage and the only option is to close the app (*Colm Cille*). In the case of the *UMA* (Universal Museum of Art), there are several exhibitions (9) and several tours (3). There are also 6 upcoming exhibitions.
The graphics of the material	2.56	For most of the museums, the graphics were well developed, and in cases where photos were used, they were high quality. There were two apps where the graphics can be changed. In one case (*Pompeii*) there were three levels—one where the user can see how the building looks now, another where the user can see how the building looked in ancient times, and a third where the user can add people into the landscape. Another app was *Bilbo* (not included in the deeper analyses), where the user could change the time of day and see how the buildings look in daylight and how they look during the night. For *Tank Tour*, all the visual elements are in high quality except the historical videos, which are in a lower quality as they were taken in a particular time. Unfortunately there were quite a few museums calling themselves a *virtual museum* where a 360° camera was used as the only technical solution (for example *Macao Museum, Battle of Batina*)
Artifacts are aesthetically manifested	2.44	In the case of the *Magi Chapel*, all the information given is about one fresco. The artefacts (art pieces) are exhibited as a whole and can be zoomed in on to see the *details at the Museum of Applied Arts Budapest*. In *Pompeii*, the artefacts are located to give an impression of how it looked in ancient times compared to how it looks now. There is also the possibility to switch on a function where you can see the people in these buildings. This helps to understand what kind of purposes the building was used for and also gives an impression of how people were dressed. In *Colm Cille*, the developers have kept the artefacts as they are now, but for some artefacts, about which it is said that they are lost, high quality solutions are used to show how they may have looked. In *Dinaledi*, the VR experience in the cave is very realistic and bones are located in the places where they were found by scientists. In *UMA*, all the exhibitions and materials are well represented and it seems like a real exhibition. *Daily Art* shows one masterpiece per day with information about it and links to other information.
Dimensions of the artifact	1.56	When experiencing the material of the *Magi Chapel*, it is easy to move around in 360° and see all the details from different dimensions. The size of this *Magi Chapel* was based on the original architecture and dimensions but it is not possible to move things around. Possibilities to see artefacts from different dimensions were only available for a few museums (*Civilisations, Colm Cille, Magi Chapel*). It was possible to see art pieces' smaller details by zooming in on the details. In *Colm Cille* it is possible to read about the majority of the artefacts, but there are some that can only be seen in the hall and are not reachable.

Table 1. *Cont.*

Technical Solutions		
Criteria	**Avg. Mean**	**Comments**
Transferability of the artifact	1.36	Just a few virtual museums provided the opportunity to transverse the artefacts in detail. For some of the museums it is not necessary to transform the art pieces if the details can be zoomed in on, but historical museums or technical museums would benefit from such an option. Artefacts are easy to transverse in the *Civilisations* app and some of the artefacts are transversable in *Colm Cille*. In the *Pompeii* app it was possible to transverse part of the building to see how it looked in ancient times and part of it could be left in the way it looks now to see the contrast.
Interactivity of the material	1.56	Only a few materials have been developed to ensure the users' interaction with the museum. In most cases, the only interactivity is to choose the sequence of the information and the possibility to zoom in on the picture. In *Pompeii Touch*, the material can be transferred and the visitor can look at the artefact as it looks now, the scene can be changed to see how it looked in times when people lived there, and people can be added to the scene. Some artefacts are movable. For *Magi Chapel*, the user can choose a point on the fresco they want to listen and learn about, and the background will change to the one they pick. This is the only form of interactivity between this product and the experiencer. In *Pompeii* it is possible to interact with the material by adding people and changing the landscape from that of ancient times to nowadays and vice versa by using the erase function. In *Colm Cille* it is possible to transverse artefacts and interact with the scene.
Possibility to interact with the narrator	1.06	Of all 36 museums, only two had an option to listen to the narrator. In the *Nikola Tesla Experience* it was Tesla himself who told the stories, and in *Dinaledi* although the narrator was not visible, information was given in audial form. There were no apps where the user could interact with the narrator.
Possibilities for people with special needs	1.14	There were only a few museums where some special features were provided for people with special needs. In *Civilisations* and *Tank Tour* it was possible to change the size of the text. For some apps, there was a possibility to get the same information in written and audial form. No other specific features were developed.
The risk of cybersickness	2.53	Cybersickness, which can be an issue in virtual reality, was not a problem in most of the virtual museums because there was an option to see the material without using VR glasses. Only one app (*Dinaledi*) can possibly cause problems with cybersickness because it takes quite a long time to go through the red gates, which can be challenging for those who do not like flashing images. It is easier to go through these gates on a screen but it is disturbing with VR glasses and there is no reason to make the journey so long.
Perception of the material	2.44	Most of the museums are well developed and their information is easy to perceive. It is only in *Colm Cille*, due to the terms used in the information provided about the artefacts, that it is sometimes hard to grasp what is meant. These terms will largely only be understandable for those who are interested in a particular subject or particular historical period, unless additional information is given before the use of the app.

Table 2. Evaluation of information architecture.

Information Architecture		
Criteria	**Avg. Mean**	**Comments**
Structure of the information provided	2.25	Most museums have well-structured information, but some apps' academic vocabulary or terminology might be hard to understand for some of their audience: For example, in the *MagiChapel* app, Renaissance, Palazzo Medici Riccardi, and frescoes. Some of the terminology contains Italian terms. Hence, this educational material requires historial knowledge on the part of its audience. In *Colm Cille* most of the information is structured very well but some objects that are included in the app can be seen but are not reachable and information about them is not given.
Information provided during the use of the material	2.11	Information about artefacts or art pieces is provided for most of the museums, but in some cases it is very short (*Pompeii Touch*). In *Magi Chapel*, some parts are hard to understand without prior knowledge of Italian history, such as the Medici family during the Renaissance, painting materials, light sources and art historical terms like portraits, perspective and symbolism. This material requires knowledge of Italian history, art history, the Italian language, and religion. However, the audience will have different levels of understanding. The experiencers who are well-educated in history will get a deep and full understanding of this material. On the contrary, experiencers who lack historical knowledge will miss some of the information provided by the background audio. The perfect audience for this material is someone who wants to learn about Italian history and the artistic history of the Magi Chapel. *Colm Cille* has the same problem, where prior knowledge is needed to understand the text and the context.
The sequence of information flow	2.31	In most museums the user can change the sequence of the information. In some cases, when smaller details are zoomed in on, it is possible to understand their symbolical meaning (*Museum of Applied Arts Budapest*). In *Dinaledi* there is the possibility of seeing the bones in a different sequence, but it is not possible to change the sequence of information provided by the narrator.
Information about the historical period of the artifact	2.03	For some museums a small amount of information is given, but some background knowledge is also needed to interpret the given information (*Pompeii Touch, Museum of Applied Arts Budapest, Pompeii, Houghton Revisited, Nikola Tesla Experience).* In *Magi Chapel*, the user can take a closer look at the frescoes and listen to the journey of the Magi. The date, name and art historical information are all given by the background audio. The experiencer has the opportunity to dig into Italian history and the history of Renaissance families, but some background knowledge is needed. Otherwise it is hard to understand the context.
Information about the place of origin of the artifact	2.14	Some of the museums are missing information on the place of origin of the artefact (*Pompeii Touch, Pompeii*). In *Civilisations*, all the information about the origin of the artefact is given clearly as written text. For example, it states that the mummy was discovered in Egypt. The best experience is provided in *Daily Art* where some brief information on the art pieces, the artist, the place of its exhibition, and its context is given, and links to additional information are also provided.

Table 3. Evaluation of educational value.

Educational Value		
Criteria	**Avg. Mean**	**Comments**
Additional information is given in audial form	1.72	Only 8 museums provided audial information but it was well prepared. If there was an option to choose among different languages, the researcher tried those languages that were known to them, and in these cases the information provided was very similar. Unfortunately it was possible only in a few cases to go deeper and find more information, and it was not possible to find out more information in audial form at any museum.
Additional information is given in written form	1.58	In most cases, written information was provided. In some cases, it was very short and not sufficient to understand the context (*Pompeii Touch, Museum of Applied Arts Budapest, Pompeii, Houghton Revisited, Toile de Joy*). There were only a few museums where, besides the information that was provided in the app, links to other information were added (*Tank Tour, Daily Art, Dinaledi*) or other sources could be opened in the same app (*Magi Chapel)*. In most cases it was written information.
Connectivity with other information	1.72	Only a few museums (*Pompeii Touch, Civilisations, Colm Cille, Tank Tour)* provided some connectivity with other information provided in the museum. For example, *Magi Chapel* gives information not only about the Magi Chapel but also the history of Florence, the religious meaning of each symbol, the atmosphere of the Renaissance and each member of the Medici family. Each part of the information is smoothly connected with the others. This material contains many historical facts. In *Dinaledi* an option is provided whereby the user can open a link to the museum itself and find much more information.
Knowledge test	1.17	Virtual museums usually do not provide the option of a knowledge test. This test is only provided in *Colm Cille* and if your answers are not correct, you can try again. Different questions are asked each time to ensure that knowledge is being tested.
Elements of gamification	1.14	Although principles of gamification are often used for educational purposes in virtual museums, these elements were very seldom used; one element is included in *Magi Chapel*—to explore the historical jewel of the Magi Chapel. In *Civilisations*, golden points can be collected for each artifact. In *Pompeii*, the option to 'erase' a building to see how it looked in ancient times gives some game-like feeling.
The material challenges the user to find out more information	1.31	Most of the virtual museums do not challenge the user to find out more information unless they are personally interested in a topic. Some elements of a challenge can be found in *Civilisations* as the user must pick artefacts by moving the globe. In the *Nikola Tesla Experience*, the way that the narrator (Tesla) tells the user the information can be assumed to be a challenging element. In *Tank Tour*, the possibility to climb in the tank and the historical videos can be seen as motivators to find out more information. *Daily Art* is great because the sentences in the text are formulated in a way to invite the user to search for more information. *UMA* material is so well prepared that it challenges the user to find out more about particular art pieces and their artists.
Focus of attention	1.61	There are very rare cases where specific features are developed to support the focus of attention to introduce some information. Some elements can be found when a figure is zoomed in on or an artefact can be transverse, but from the educational perspective, the focus of attention is supported in following virtual museums—*Pompeii Touch* (to find particular buildings), *Magi Chapel* (to see all the details and follow the information), *Civilisations* (to move the globe and find artefacts and information about them), *Pompeii* (because there are three levels to how the buildings can be seen), *Colm Cille* (because it is possible to move the artefacts), the *Nikola Tesla Experience* (because the narrator (Tesla) speaks in an encouraging manner), *Tank Tour* (because of the different forms of information provided), and *UMA* (because the exhibitions are created in an interesting way and the information provided is written in a way that encourages the user to read it all).

5. Discussion

In his work, Fowler [47] emphasizes three stages of learning through VR that can also be taken into account for virtual museums: (i) Conceptualization; (ii) construction, and (iii) discussion. It is in the light of these stages of learning and from the perspective of the analyzed virtual museums, it can be concluded that in the conceptualization phase, where a student should learn and interpret facts, concepts and theories, it is possible to learn facts through a virtual museum's information and to receive additional information about it. But the teacher must check to ensure that the learning path of the students has been successfully selected and the development of cognitive processes is underway if they are to acquire the skills to interpret facts and concepts. Only in one of the analyzed applications (*Colm Cille*) was there a built-in knowledge assessment test, but it was more focused on testing memory processes for factual knowledge; the opportunity to interpret the facts presented in the applications was not included in any of them.

The second stage is where the learner has to construct new knowledge or competences using learned facts and concepts in new contexts and compare different experiences. In short, none of the virtual museum applications analyzed provided such an opportunity, so the support of a teacher is needed here too to provide this knowledge, which can be done through discussions and group work, including on information gained from virtual museums and information provided by teachers. This means that the third stage can then be reached through the pedagogical work of a teacher.

Considering learning in museums as a form of active learning, the potential for virtual museums exists. This was seen in virtual museum applications that showed specific locations (*Dinaledi, Pompeii, Toile de Joy)*. Even better if the application provided the possibility to interact with artefacts (*Civilisations*), interact with the narrator (*Nikola Tesla Experience*) or explore art pieces in detail (*MagicChapel, UMA)*. This can both ensure that individual reflection is triggered, while interacting with the nature and concreteness of the museum's intangible artefacts [16], and support culturally responsive teaching [17], thus, scaffolding the learning of new knowledge. Thus, virtual museums can be considered as learning agents [28] for upward learning curves, as such solutions can help broaden the spectrum of collaboration with digital materiality and help visualize and spatialize abstract concepts [23], and involve learners as co-designers and co-researchers [57]. Museums can be used as situated learning spaces [14,15], but during the evaluation process it was found out that only a few aspects of situated learning were introduced in apps of virtual museums; therefore, this requires the presence of a teacher seamlessly manipulating various tools [14], sometimes a virtual museum to foster learners' interest, but sometimes additional information provided by the teacher to ensure that the information provided in the virtual museum has the proper context, because in order to appreciate a work of art it is also necessary to know about forms of artistic expression and the symbolic meaning of the artwork. As it suggested by Aguayo, Eames, and Cochrane, learning through mobile applications should be authentic to the context, integrated within and across learning areas and scaffolded for a clear learning pathway [20], and there should be interconnection between the virtual world and physical action [58] to ensure authentic mobile learning [22]. Such synergy between different pieces of information will help to develop advanced knowledge and contribute to the development of metacognitive processes.

The teacher needs to ascertain the level of knowledge of the learner, so a knowledge assessment is needed to ensure that the learner has understood the information received and is able to interpret and apply it in other contexts. If this is not technologically possible through a virtual museum, then the teacher should provide it.

The reception of feedback supports the learning process, but the downside is that the provision of feedback was not possible in any of the virtual museums, so it is necessary to get this feedback from the teacher instead, which indicates that beyond the information architecture criteria being evaluated here, it is also necessary for virtual museums to include some features that allow feedback to be given.

There are only a few applications where it is possible to change the way information is received, and it can be concluded that this type of learning contributes to some extent to inclusive education from the perspective of accessing information in museums through an application, such as providing people with mobility issues or disabilities (reduced mobility, socio-economic situation) with access to this knowledge. However, in most of the evaluated virtual museum applications, it is not possible to change the way information is received because it is not possible to change the language, to switch between written and audial information (or vice versa), or to turn on sign language. This confirms that not all principles of inclusive education have been taken into account, and these must be considered both from an information architecture point of view and from a technological perspective. If a teacher wants to use one of the applications to make the learning process more interesting, he or she must evaluate the specific needs of the learners to ensure that all learners have equal access to information.

Although there are articles that have analyzed the role of virtual narrators [7] or the user of the virtual solution having a sense of presence [10], unfortunately only two of the applications analyzed used a narrator and only one was human-like, which shows that this potential is not yet being fulfilled.

The results of this analysis of virtual museums echo those of Quinn [32], in that the role of the teacher in this network of agents is still very important because the virtual solutions available today cannot completely replace human pedagogical work, as also concluded by Garzón and Acevedo [6].

Of the 36 applications analyzed, 24 had a mean of over 2 (out of 3) in their technical performance, and information architecture criteria and were structured sequentially and logically to ensure that the information included was easy to read. The artefacts in these 24 applications were also aesthetically pleasing to ensure that people will most likely use these apps. Unfortunately, there were 12 apps which were of low quality, and this means that a third of them are not really usable.

Meanwhile, in terms of the educational value criteria, only six of the evaluated virtual museum applications' mean is 2 or higher, which means that while most freely available applications can be considered as learning agents that stimulate interest, supplement existing knowledge with new knowledge and provide a change in forms of learning, they cannot be considered as full-fledged learning agents that completely replace the teacher's work.

It should be noted that this study has limitations, the first of which involves selecting only those virtual museum applications that are available to the user free of charge. The results may be different for applications for which there is a charge. The second limitation is that despite the fact that the evaluation of virtual museums was carried out using a structured evaluation, it still involves an aspect of subjectivity, since the evaluation was carried out by a person with a certain amount of technological experience, pedagogical principles and information architecture conditions, as the valuations are largely due to the evaluator's current knowledge. This limitation can be mitigated, albeit not completely eliminated, by the continuation of research activities, the expansion of the research base and the development of deeper details of the evaluation section.

Despite these limitations, the study can be considered useful for:

i) Educators who want to expand their learning environment by offering virtual museum solutions;
ii) Learning designers, who will want to evaluate their developed virtual museums from the three perspectives on offer;
iii) museum staff who want the materials they offer to be used not only for entertainment, but also for educational purposes.

6. Conclusions

Only one application (*Colm Cille*) had built-in knowledge assessment test focused on testing memory processes for factual knowledge; the opportunity to interpret the facts presented in the applications was not included in any of them.

None of the virtual museum applications analyzed provided an opportunity to construct new knowledge or competences using learned facts and concepts in new contexts.

Virtual museums can be considered as learning agents for upward learning curves, as such solutions can help broaden the spectrum of collaboration with digital materiality and help visualize and spatialize abstract concepts, but the material should be prepared to take in mind learning logic.

In summary, all the information analyzed indicates that, if virtual museums are intended to promote knowledge and cognitive development, the material alone can only be used without the teacher's seamless presence if the individual is very interested in a particular subject and has prior knowledge in order to understand the information, or if he or she is highly motivated to seek additional information on his or her own. Otherwise, the active involvement of a teacher is needed to use such technological solutions to interest students in a subject. Unfortunately, the range of applications is not yet considered sufficient to provide learning in museums, where they also have a significant educational value, but they can be used as learning agents if the teacher evaluates the application in advance to understand what pedagogical activities are needed both before and after using the virtual museum.

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Acknowledgments: These findings provide a basis for further research into virtual museums, such as their use in educational settings to assess their impact on learning outcomes, pupils' metacognitive load, learning preferences, learning outcomes, and so on.

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Appendix A

Criterions for the evaluation of VR/AR experiences in museums.

All the criteria should be evaluated by ticking the correct level according to the evaluator's opinion. Only in the last row, where the evaluator's opinion on the age group should be given, can more than one answer be chosen.

The list of criteria includes three evaluative aspects:

1. Technological solutions
2. Information architecture
3. Educational value

Structure of the material	The content is well structured	The content is structured but the structure is not logical	The content is fragmented and not structured according to some kind of logic
	☐	☐	☐
Comments can be added here:			
Use of the material	It is easy to understand how to use the material	It is not very understandable how to use the material	It is hard to understand how the material should be used
	☐	☐	☐
Comments can be added here:			
The graphics of the material	The graphical elements are well structured and visualizations are in high quality	The graphical elements are randomly structured and visualizations could be of a better quality	The graphical elements are poorly structured and visualizations are in low quality
	☐	☐	☐

Comments can be added here:			
Artifacts are aesthetically manifested	All artifacts are represented by the harmonious coming together of the parts; the juxtaposition of the structural elements in space represents the identity of the design through its composition or configuration	The main artifacts are aesthetically manifested, but there are some problems with the juxtaposition of the structural elements or with their composition or configuration	There are quite a lot of problems with the juxtaposition of the structural elements in space and their composition or configuration
	☐	☐	☐
Comments can be added here:			
Dimensions of the artifact	It is easy to move the artifact and see it from different dimensions (outside and inside)	It is possible to move the artifact and see it from different outside dimensions	It is possible to see the artifact only from a few outside dimensions
	☐	☐	☐
Comments can be added here:			
Transferability of the artifact	It is easy to transverse the artifact in smaller details	It is possible to transverse the artifact in a few details	It is not possible to transverse the artifact in detail
	☐	☐	☐
Comments can be added here:			
Interactivity of the material	There are different forms of interactivity	There is some interactivity	People cannot interact with the material
	☐	☐	☐
Comments can be added here:			
Possibility to interact with the narrator	There is a possibility to talk with the narrator (visible person)	There is a narrator (visible person) who provides information but there is no possibility to interact with him/her	There is no narrator present as a visible person
	☐	☐	☐
Comments can be added here:			
Possibilities for people with special needs	The material is prepared in a way that people with diverse special needs can use it, and it is clearly indicated how to use it	The material is prepared in a way that people with some specific special needs can use it, but it is not available for all groups of special needs, and it is indicated which groups can use it	The material is prepared for the general public, and there is no possibility to switch the way in which the information is provided
	☐	☐	☐
Comments can be added here:			
The risk of cybersickness	The risk of cybersickness is completely reduced	The risk of cybersickness can be a problem for some groups of people	There is a high risk of cybersickness
	☐	☐	☐

Comments can be added here:			
Perception of the material	It is easy to perceive the material	The material is well prepared but sometimes it is hard to perceive due to the complexity of the information	It is hard to perceive the material
	☐	☐	☐
Comments can be added here:			
Structure of the information provided	The information provided is well structured and easy to understand	Some parts of the information are well structured but some information lacks structure and it is not easy to understand	There is no structured information provided
	☐	☐	☐
Comments can be added here:			
Information provided during the use of the material	All the information is given in an easy to understand way even without previous knowledge on the topic	Some parts of the information are given in an easy to understand way, but some parts are hard to understand without previous knowledge on the topic	The information is hard to understand (due to complexity, fragmentation or other problems)
	☐	☐	☐
Comments can be added here:			
The sequence of information flow	The sequence of the information flow can be changed according to the decision of the person who explores the material	Some parts of the information can be skipped or changed	The sequence of the information flow cannot be changed according to the decision of the person who explores the material
	☐	☐	☐
Comments can be added here:			
Information about the historical period of the artifact	Information about the historical period is given and it is clear to understand	Information about the historical period is given but it is hard to understand	Information about the historical period is not given
	☐	☐	☐
Comments can be added here:			
Information about the place of origin of the artifact	Information about the place of origin of the artifact is given and it is clear to understand	Information about the place of origin of the artifact is given but it is hard to understand	Information about the place of origin of the artifact is not given
	☐	☐	☐
Comments can be added here:			
Additional information is given in audial form	A lot of additional information in audial form is given	Some additional information in audial form is given	No additional information in audial form is given
	☐	☐	☐

Comments can be added here:			
Additional information is given in written form	A lot of additional information in written form is given	Some additional information in written form is given	No additional information in written form is given
	☐	☐	☐
Comments can be added here:			
Connectivity with other information	There is smooth connectivity with other parts of the information, other artifacts, other historical facts, etc.	There is fragmented connectivity with other parts of the information, other artifacts, other historical facts, etc.	There is no connectivity with other information
	☐	☐	☐
Comments can be added here:			
Knowledge test	The possibility to test knowledge is included in different parts of the material and on different aspects of the information provided	There is a possibility to test knowledge, but it is only on a few aspects of the material	There is no possibility to test the knowledge included
	☐	☐	☐
Comments can be added here:			
Possibility to organize group activities	It is possible to organize group activities for an unlimited number of participants	It is possible to organize group activities for small groups (up to 3 people)	It is not possible to organize any group activities while interacting with the VR experience
	☐	☐	☐
Comments can be added here:			
Elements of gamification	Elements of gamification are used to attract people and to keep them focused	Some elements of gamification are used but on a fragmented basis	Elements of gamification are not used
	☐	☐	☐
Comments can be added here:			
The material challenges the user to find out more information	The material is developed in a way to challenge the user to find out more information	There are some elements that challenge the user but these are not used on a regular basis	The material does not challenge the user to find out more information
	☐	☐	☐
Comments can be added here:			
Focus of attention	The material is developed in a way that keeps the user's attention focused on the experience all the time	There are some parts where the focus of the user's attention is stimulated but not throughout the experience	The material is interesting but there are no specific features to capture the attention of the user
	☐	☐	☐
Comments can be added here:			
The age group for which the material can be used	Adults (18+)	School-age children (7-18)	Minors (up to 7)
	☐	☐	☐
Comments can be added here:			

Appendix B

The list of analyzed VR museums

1. Chateu de Versailes
2. PompieTouch
3. NEFERTITI VR by EON
4. National Museum of Iraq
5. Macao Museum
6. Bosch VR
7. MagiChapel
8. Civilisations
9. Memory Museum
10. Batle of Batina Memorial museum
11. Universal Museum of Art
12. Toumanian museum
13. Museum of Applied Arts Budapest
14. Pompeii
15. Houghton Revisited
16. Colm Cille
17. Never built New York
18. Nicola Tesla experience
19. Asolo
20. Haramain exhibition
21. Bilbo
22. Museo del San Michele
23. Viewmuseum
24. Tank tour
25. Hermes
26. Hermitage
27. Daily Art
28. Muzeum Archeologiczne
29. BMW museum
30. Rijks Museum
31. Edu Must
32. Toile de Joy
33. Museum of Portimao
34. Dinaledi
35. Solar System
36. Museum of Architecture

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