

A High-Level Tool for Curators of 3D Virtual Visits and its Application to a Virtual Exhibition of Renaissance Frescoes

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Abstract

This paper presents a high-level tool to build 3D virtual exhibitions from pre-existing 3D models and design virtual visits. Our tool exploits AI techniques and careful interaction design to require minimal technical knowledge by a curator, and allows one to: (i) easily arrange 3D models (e.g. of artworks) in a virtual space; (ii) find, through an assisted procedure, interesting points of view in the virtual exhibition, and add multimedia information to them; (iii) design virtual visits that connect those points of view to form interactive tours with various levels of navigation assistance for the visitor. Moreover, we show how the tool has been used to build the virtual visit of a church with important Renaissance frescoes.

1. Introduction

Despite several advances, deriving and using 3D models of tangible Cultural Heritage (CH) is still far from becoming the everyday practical choice for digital documentation, reconstruction, and presentation, as evidenced also by the existence of large research projects on this topic (e.g. the 3D CO-FORM Project [Arn09] and part of the FOCUS-K3D project [Vav08]). As acknowledged by these projects agendas, one of the open issues is how a curator or a CH expert can easily, and possibly without the help of 3D graphics and computer professionals, use already acquired 3D models of artworks and environments to build 3D virtual exhibitions. While some projects have focused on organizing collections of artifacts into digital libraries with metadata [MW03], from which 3D virtual exhibitions can then be assembled, there is the need for tools that specifically focus on the typical curatorial tasks (arranging artworks in a space, providing explanations to visitors, designing tours for different types of visitors) while not requiring considerable technical skills or manpower. In this paper, we present a high-level tool devoted to this purpose. The innovative aspects of the application, called VEX-CMS (*Virtual EXhibition Content Management System*), consist mainly in (i) using AI techniques to assist the curator in the tasks of finding interesting viewpoints of

presented artworks or environments and design tours of the exhibition with various level of interactivity and navigation assistance for visitors, and (ii) supporting an interaction with the 3D models that minimizes curator efforts.

The paper is organized as follows. Section 2 reviews related work on tools for the construction of virtual exhibitions. Section 3 presents the VEX-CMS tool. Section 4 illustrates how VEX-CMS has been used in a CH project to build the virtual visit of a church with important Renaissance frescoes. Finally, Section 5 concludes the paper and outlines future work.

2. Related Work

Virtual museums and exhibitions have been studied in different areas (e.g. human-computer interaction, 3D graphics and virtual reality, database systems) and research has been carried out on many aspects involved in their construction. For example, Patel et al. [PWWS03] reports the main outcomes of the European Project ARCO in developing a complete solution for digitizing artworks, storing them into multimedia databases together with relevant metadata [MW03], and presenting them in the context of 3D or augmented-reality exhibitions. However, there has not been much work on the

specific aspect of making the design of the interactive 3D exhibition easy for non-technical users such as curators and architects. One possibility that is often suggested is to exploit game design tools. However, as noted by one of the proponents of this approach [LV04], programmers are still needed, and work is required to remove game-specific features and ultimately adapt the logic of the tool to a different purpose. Also the approach proposed in [RK04], which has been developed in the context of the CIPHER project, provides a workflow that allows a curator to set up a virtual exhibition; however, it relies on using a general purpose modeling tool for specifying the camera movements and time line, which, as the authors admit, "requires some knowledge of the 3D design process". An alternative approach, as advocated by [VS09], is to have curators design the exhibition using a simpler 2D interface, and then automatically derive a 3D visualization from that (e.g., using operations like wall extrusion). In this way, however, the resulting 3D environments are quite simple, and 3D reconstructions of real environments cannot be used.

A related research direction concerns the problem of simplifying the creation of virtual environments for non-technical users, e.g. children. For example, Kids Movie Creator (KMC) [WLS07], a tool that allows young children (aged 7 to 12) to create interactive VEs, introduces many solutions to simplify interaction both at the conceptual and practical levels, from adopting an avatar-based interaction (i.e., the author of the VE controls an avatar that walks through the environment) to limited modeling capabilities. Alice [CAB*00] is a 3D programming environment designed for undergraduates with no 3D graphics and programming experience that allows to build VEs and program their behavior. Our work shares some of the assumptions and goals behind Alice, e.g. the fact that creation of 3D environments could be interesting for an audience that not necessarily has a mathematical and programming background, the importance of designing a 3D environment creation tool with a target audience in mind, and providing users with simple methods to specify the application logic.

Assisted navigation and automatic computation of interesting viewpoints has been experimented in the context of virtual museums, but typically for helping the visitor find its way and easily navigate through the museum. For example, the research presented in [DZ94] develops an intelligent camera control system and applies it to the task of navigating a virtual museum, using constraints to specify camera requirements. We also exploit a constraint-based approach but focus on the largely unexplored topic of using automatic viewpoint computation to assist the authoring process of a virtual exhibition. The approach proposed by Elmqvist et al. [ETT07] automatically generates a tour of a 3D virtual building that includes all landmarks; in this way, however, curators have no control on how the visitor will experience the virtual exhibition, and cannot therefore tell the story they feel is most important to convey, and in their order.

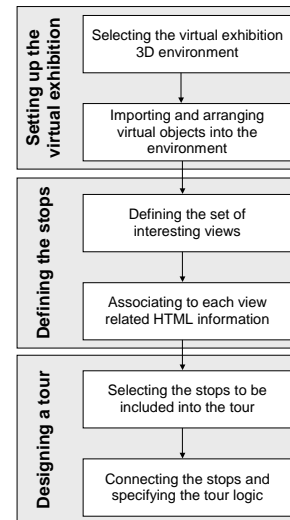


Figure 1: Workflow in VEX-CMS.

3. The Virtual Exhibition Content Management System

VEX-CMS organizes the design of a virtual exhibition in three main phases (see Figure 1): inclusion and arrangement of objects in the virtual space, identification of interesting points of view to which associate multimedia information, and definition of tours of the virtual exhibition. In the following Sections, we describe in detail each phase. VEX-CMS is not meant for object modeling purposes, in the sense of creating or modifying 3D models, since that task is typically outside the abilities of a curator or a CH expert. Therefore, to build a virtual exhibition, a curator needs existing 3D models of the virtual spaces (e.g., a building) and of the objects and artworks that are part of the exhibition. A companion application, called *VEX-CMS Viewer*, can be used by a visitor to access the virtual exhibitions produced with the authoring tool.

The idea we followed in designing the application was to closely reproduce the experience of designing a real exhibition, where the curator visits the actual exhibition space and decides how to arrange artworks and explanations. However, one important part of real exhibitions, i.e. lighting, cannot actually be managed inside VEX-CMS, but has to be carried out in the previous construction of 3D models (e.g., by placing dynamic lights or computing light maps). In the following, we use the terms *curator* to indicate the creator of the virtual exhibition, and *visitor* to indicate a user of the virtual exhibition. The term *object* indicates any artwork or furniture element that the curator wants to include in the exhibition, while *environment* indicates the virtual environment where the exhibition takes place.

The main interface of VEX-CMS (see Figure 2) is organized in two parts. The right part of the interface displays

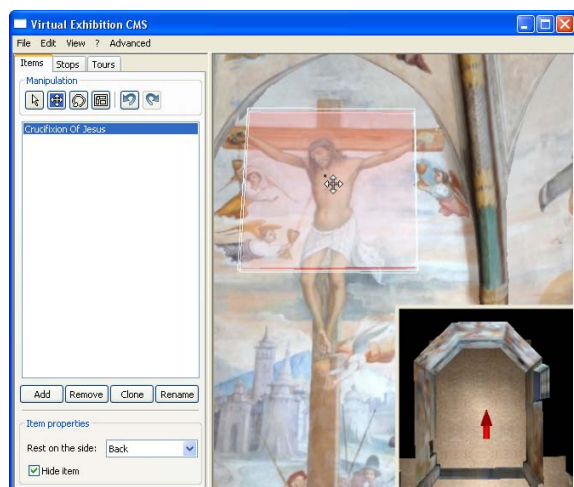


Figure 2: The main interface of VEX-CMS. On the right, a first-person view of the exhibition, augmented by an overlaid map, where the curator can navigate and arrange objects; on the left, the items tabbed pane with buttons to manage and arrange objects.

a first-person view of the environment, where the curator's avatar can walk (or fly) and arrange objects in space. The first-person view of the environment can be augmented with an overlaid interactive map, using the multiple-views layout proposed by Chittaro et al. in [CRI09] that has been determined as significantly more efficient than using just the first-person perspective in an experiment with non-technical users. The left part of the interface is characterized by three tabbed panes (*items*, *stops* and *tours*), one for each phase that has to be carried out to build a virtual exhibition.

3.1. Object Arrangement

In this phase, the curator includes objects in the environment and arranges them with translation, rotation and scale operations. Since precise 3D arrangement can be a hard task for curators, there is the possibility of specifying the side of the object that should stay attached to adjacent geometry. In this way, whenever the object is not attached to anything on the specified side, it will "fall" in a direction perpendicular to that side (e.g. down, if bottom is used as the chosen side) until it finds a geometry on which to stand. Then, the object can be easily moved, without compenetration with other geometries, by sliding it on the specified contact side.

Sometimes, relevant elements of the exhibition (e.g., frescoes) are intrinsically part of the environment. Since we currently do not rely on semantic annotations in 3D content, to simplify the process of associating multimedia explanations to specific parts of 3D models (and also to use information about their position in the design of tours, see Section 3.2), a



Figure 3: The result of computing a VOI from a list of six sculptures in a museum room.

curator can also add and place "invisible" bounding geometries (that appear to the curator as semitransparent geometries, but are not visualized to the visitor) to mark interesting regions of a 3D model and have the application consider them as separate objects. In Figure 2, for example, the curator has placed an "invisible" box-shaped geometry on the wall for identifying a specific part of a fresco as an individual item of the exhibition. This is obviously just a workaround (but effective) solution which could be avoided provided that proper semantic information is added to 3D models of CH objects and environments.

3.2. Defining the Stops

In our approach, a *Stop* is constituted by a *View of Interest* (VOI) in the virtual exhibition and related HTML information that is displayed on a 2D overlay. A VOI can be defined in two ways: the first one is by providing a viewpoint in the virtual exhibition (manual procedure), and the second one is to define a set of objects that should be seen in the VOI (assisted procedure).

In the manual case, the curator simply defines a VOI by "taking a picture" from her current point of view. In this way, defining a VOI requires one to navigate the environment until the desired view is reached.

In the assisted case, the curator chooses which (visible or invisible) objects need to be included in the VOI and their relative importance, and then a VOI that displays them is automatically computed using an algorithm based on the declarative approach to camera composition described in [BDGER08]. More specifically, starting from a list of objects (ordered by importance by the curator), VEX-CMS generates for each object a set of requirements stating that: (i) the object must be entirely visible and less occluded as

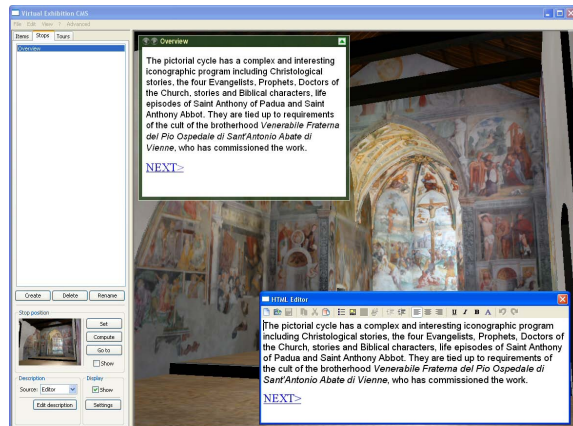


Figure 4: The interface of VEX-CMS to define a stop. On the left, the tabbed pane including the list of stops, and buttons to define the VOI and edit the description of the currently selected stop. On the right, the HTML editor (bottom-right panel) and the preview of the description (top-left panel) overlaid on the exhibition view.

possible in the image rendered from the viewpoint; (ii) it should be visualized from a proper side (typically, from the front); (iii) its size, as seen from the viewpoint, should be as big as possible (to let the user appreciate it in most possible detail). Then, a constrained optimization process searches inside the space of all possible viewpoints using a global optimization strategy that returns the viewpoint maximizing the combined satisfaction of the generated requirements. In the cases when not all requirements can be fully satisfied, the procedure will give precedence to the objects which have been deemed as more important, and will try to satisfy requirements as best as possible (e.g. allowing small occlusions or reducing the size of objects in the image generated from the viewpoint). For example, Figure 3 shows the result of an assisted VOI computation where the objects of interests where six sculptures in a museum room (deriving a sort of "overview" VOI). When the computation of the VOI ends, the result is shown to the curator. Then, the VOI can be used as it is or refined with manual navigation (e.g. slightly changing the position or orientation to get a better view). Alternatively, the curator can manually modify the generated list of requirements (e.g. removing some of them) and start again the automatic process. The assisted VOI derivation procedure is described in full details in [CIR10].

For each stop, the curator can add explanatory information in the form of local HTML pages or URLs, whose content is displayed in a 2D overlay through an HTML rendering engine. Additionally, a simple integrated WYSIWYG HTML editor can be used when a few lines of textual descriptions with some images are sufficient (see Figure 4). Moreover, for each description the curator can set some visualization

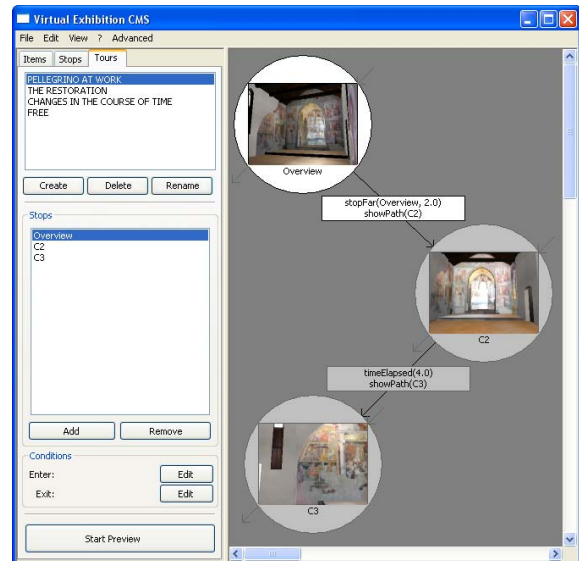


Figure 5: The interface for defining a tour. Stops are shown as icons in the right part of the interface, they can be arranged spatially and then connected by drawing arcs among them.

parameters, such as the size and alignment of the 2D overlay used for the presentation.

3.3. Designing Virtual Tours

Once stops have been defined, the curator can connect them to create tours that a visitor can follow. Each tour is displayed to the curator as a graph where stops are nodes, and possible transitions are represented as directed arcs connecting them (see Figure 5). The curator graphically lays out the necessary stops on a plane, and draws transitions as lines between them. For each transition connecting two stops, the curator selects the *condition activating the transition* and how the transition is performed (*navigation action*). Moreover, for each stop of a tour, the curator can define general *enter* and *exit conditions*. After defining every detail of a tour, the curator can preview what the visitor will see. In the following, we present the logic of tours, while in Section 3.3.1 and Section 3.3.2 we respectively describe the conditions and navigation actions that are currently available.

The creation of a tour defines a finite state automaton, where states correspond to stops, and therefore, at each moment of a visit to the exhibition, only one stop will be active. The automaton also includes an additional state (*default state*) which does not correspond to any defined stop. The default state is active whenever (i) no other state is active, and (ii) no enter condition is true. As soon as one enter condition becomes true, the corresponding stop is activated, i.e. its VOI becomes the visitor viewpoint, and its informa-

tive content is displayed to the visitor. This stop remains active until the exit condition, or the activation condition of an outgoing transition the current stop, becomes true. In the first case, the current stop is deactivated and the corresponding description hidden. In the second case, the corresponding navigation action is executed and the current stop deactivated. At the end of the execution of the navigation action, the destination stop is activated and the corresponding description visualized.

3.3.1. Conditions

VEX-CMS supports three different types of conditions to activate stops or transitions. The first type concerns mouse actions on (visible or invisible) objects of the virtual exhibition (*itemSelected*) and on links of HTML descriptions (*linkSelected*). The second type considers spatial relations (e.g., proximity) between the visitor and one object or stop of the exhibition. This type of condition allows one to identify when the visitor comes close or moves away from an item (*closeToItem* and *farFromItem*) or stop (*closeToStop* and *farFromStop*). For example, a *closeToStop* condition can be used to activate a stop. The third type concerns the time elapsed since the activation of the current stop (*timeSpent*). All conditions allow to specify additional parameters (e.g., the *timeSpent* condition allows one to specify after how much elapsed time the condition is true).

3.3.2. Navigation Actions

The transition between stops can be executed in three possible ways:

- teleporting the visitor to the destination stop (*teleport*);
- automatically walking or flying the visitor to the destination stop (*transport*). In this case, an animation will lead the visitor to the stop, e.g. simulating a walk;
- drawing a path to the destination stop (*showPath*). In this case, the visitor has to manually navigate the environment following the visual help provided by the drawn path.

The *transport* and *showPath* actions require the computation of a collision-free path connecting two stops. For path planning, we adopt a cell decomposition approach. In particular, using an automatic approach similar to the one described in [IRC04], for each room of the environment (which is defined by bounding volumes) VEX-CMS derives a raster image in which each pixel corresponds to an area of the virtual room and the color of the pixel indicates whether the corresponding area contains a geometry (i.e., cannot be navigated) or not. The path planner uses such images as well as connectivity information between rooms for building an adjacency graph, i.e. an undirected graph in which nodes corresponds to navigable areas while edges indicate if two areas are adjacent. Then, we compute collision-free paths in two steps, as in [Kuf99]. First, we derive the sequence of nodes that connect the start and end position by using Dijkstra's algorithm. Second, we compute a collision-free path connect-

ing the centers of the cells corresponding to the sequence of nodes obtained from the previous phase.

This approach for specifying tours allows curators to define different types of tours, ranging from completely constrained visits (i.e. the visitor is transported through the environment and the informative contents is automatically displayed) to free visits (i.e. the visitor can freely navigate through the exhibition and access the descriptions, e.g. by clicking on the items into the environment). The *showPath* transport is one of the possible navigation aids that could be added to help visitors in navigating the exhibition without getting lost. Some examples of guided and free tours are illustrated in Section 4.2.

4. A case study: the Church of Saint Anthony Abbot

VEX-CMS has been tested in the *InfoBC* CH project (<http://infobc.uniud.it>) to build a virtual exhibition of the Church of Saint Anthony Abbot in San Daniele del Friuli (North-Eastern Italy). The choice of this church comes from the need to gather and make accessible the rich documentation found in historical archives about the most important Renaissance frescoes of the region painted by Martino of Udine, better known as Pellegrino of San Daniele (1467 or 1472 - 1547). Considered information sources include the historical library "Biblioteca Guarneriana" in San Daniele and the Monuments and Fine Arts Offices of Udine and Venice. Detailed artistic information can be found in [SV09].

The 3D model of the church has been obtained through the opportune simplification of survey data acquired by means of a laser scanning and photogrammetric integrated system. In the following, we first summarize the main phases required for the 3D model acquisition, and then we describe how VEX-CMS has been used for creating virtual tours inside the obtained 3D environment.

4.1. 3D Model Acquisition

The photorealistic 3D model of the church has been obtained thanks to a surveying performed with a *Terrestrial Laser Scanning* (TLS) and photogrammetric integrated system (*Riegl Z390i* TLS system integrated with a *Nikon D200* digital photogrammetric camera).

In the first phase, the TLS and imaging instrument was placed inside the church in three different positions. Eleven point clouds were automatically acquired with different TLS Z-axis orientations and angular scanning steps, for a total amount of 18 millions of 3D points. From the same scan stations, 100 digital metric images (3872x2592 pixel, 20 mm focal length *Nikkor* objective) were acquired by means of a controlled panoramic rotation of the camera fixed onto the TLS top. A similar data acquisition was performed outside for the main gothic facade, achieving seven scans (15 millions of points) and 63 digital images. As a result, this phase

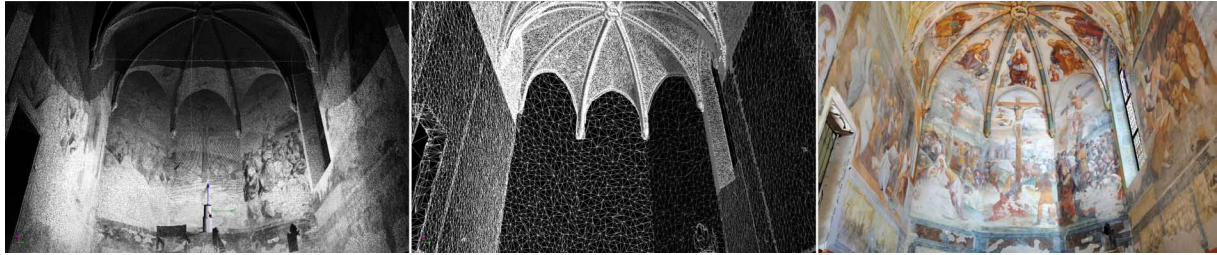


Figure 6: (left) View of the three point clouds acquired from the center of the apse colored by gray-values according to the intensity of the returned laser beam; (middle) wireframe view of the triangulated model after the optimization process; (right) textured model of the apse and presbytery.

allowed us to automatically collect in few hours about 33 millions of points (351 Mb) and 163 images (621 Mb).

In the second phase, obtained point clouds have been locally registered and globally geo-referenced using the *RiSCAN PRO*© software. For this purpose, 41 high-reflectivity targets have been placed inside and outside the church to analytically estimate the involved 3D rotations. The left image in Figure 6 shows the result of three acquisitions performed using different TLS orientations and after the registration and geo-referencing processes, using shades of gray to indicate the intensity of the returned laser beam.

The third phase concerned the triangulation process aimed at deriving a *Dense Digital Surface Model* (DDSM) from the acquired point cloud. First of all, points of the cloud have been manually grouped in 27 subsets, each one representing a different part or element of the church that will be processed separately to produce a mesh. The 27 meshes have been optimized thanks to a procedure of smoothing and decimation (CORSIVO). This phase reduced to 315K the total number of triangles of the church model: about 68% of them model the curved surfaces of the apse and presbytery vaults (see middle image in Figure 6).

The last phase concerned the texture mapping. This phase was completely automatic since in our case the camera was firmly fixed onto the TLS top and this allows one to know the position and orientation of camera used for taking each image. As a result, the texturing was performed by applying the photogrammetric equations of collinearity to each vertex of the 3D model (see right image in Figure 6). More detailed information on the laser scanning and 3D modeling operations can be found in [VSM09].

4.2. Virtual Tours of the Church

We have created one free tour and three guided tours, each one focused on a different cultural aspect, to provide virtual visitors with historical and artistic information as well as information on restoration works. These tours have been composed from around 20 stops, corresponding to relevant fres-

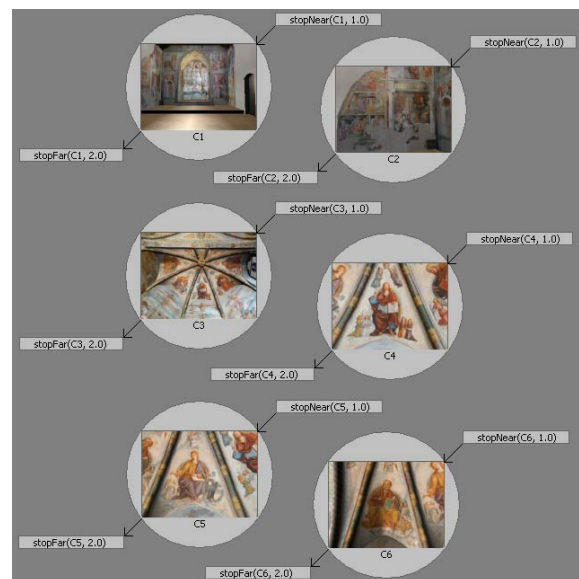


Figure 7: The VEX-CMS interface displaying the design of the Free tour.

coes or details of them. The corresponding VOIs have been derived by using both the manual and assisted procedures. In particular, the assisted modality has been useful to reduce the time needed in navigating the environment to reach a proper viewpoint for appreciating frescoes that would appear too small by standing on the church floor.

The description of each stop has been mostly created using the HTML editor integrated in VEX-CMS, in some cases inserting links to access further information from CH regional and national databases. This solution has been favored over creating full HTML pages, which would have required the help of a Web designer.

In the free tour that has been defined (illustrated in Figure 7), the visitor can navigate inside the church and observe in any order the scenes and figures frescoed. To define this type

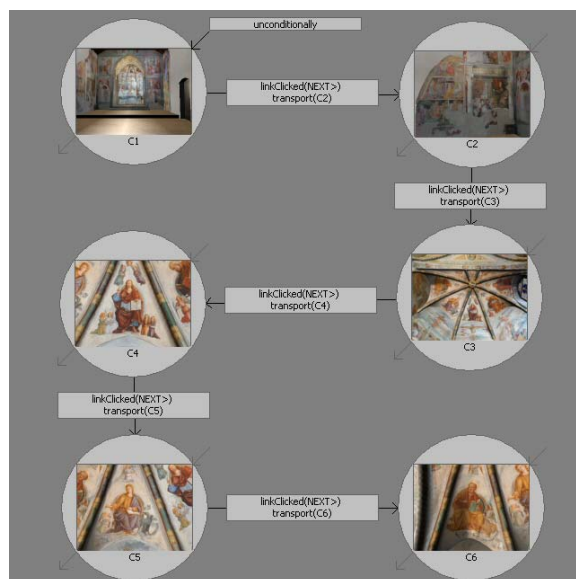


Figure 8: The VEX-CMS interface displaying the design of the "Pellegrino at work" tour.

of tour, each stop has been provided with an enter and exit condition, without defining any transition. Instead, we used just *closeToStop* for the enter conditions (a stop is activated as soon as the visitor is sufficiently near to it), and *farFromStop* for the exit conditions (a stop is deactivated as soon as the visitor walks away from it).

The remaining three tours guide the visitor following an ordered sequence of stops. Mostly, we used *transport* navigation actions for the transitions, and *linkSelected* as the condition activating the transitions, also inserting a *next* link (activating the transition to the next stop of the tour) into each description. For example, Figure 8 illustrates the "Pellegrino at work" tour, where stops, representing the relevant scenes painted by Pellegrino, are connected sequentially following a chronological order.

The tour called "The restoration" displays archive documents to provide a CH expert or student visitor with information on the preservation history of frescoes and on the controversy that occurred, during the centuries, between the City Council of San Daniele (the owner) and the Monuments and Fine Arts Offices. For example, the stop depicted in Figure 9 is focused on a detail of the apse vault frescoed by Pellegrino of San Daniele representing the Blessing Christ in the almond (in the center) and four Apostles (Luke and Matthew at right, John and Mark at left). The description of this stop accesses a remote digital document (left part of Figure 9) in a CH regional database. Finally, the guided tour called "Changes in the course of time" presents the structural works performed on the church over the centuries to preserve

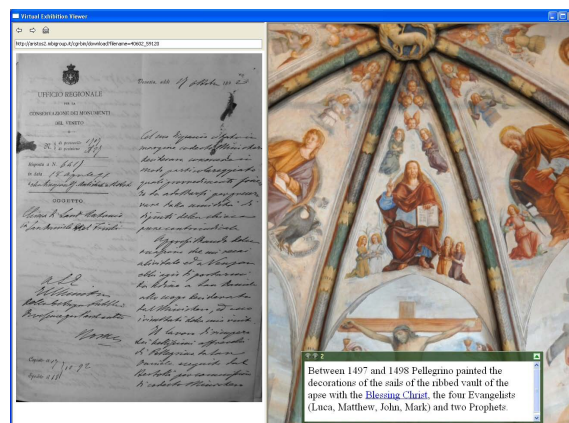


Figure 9: The stop of the "The restoration" tour presenting the first fresco painted by Pellegrino between 1497 and 1498 in the vault of the apse. On the left, a digital document fetched from a national CH database about the history of the preservation of historical art objects

the frescoes from the decay caused by the continued water infiltration and aesthetic reasons.

The design of such tours (each consisting of 7 to 9 stops), in terms of operations with the application, was done in minutes, and the possibility of previewing a tour as soon as it had been defined allows for rapid evaluation by the CH experts. Additionally, guided tours were used to rapidly produce movies of virtual walkthroughs that can be easily exchanged among CH experts or distributed to students.

On the negative sides, the CH experts had difficulties in defining proper sizes and positions for the 2D overlay that display the information about the artworks. First, the size of the overlay had to be often adapted to fit descriptions with big images; second, especially while previewing free tours, sometimes the overlay was hiding the artworks it referred to. An interesting possibility would be to use the same assisted viewpoint derivation method to find, during the visit, a proper size and position for the overlay such that the artworks included in the current VOI would not be occluded.

5. Discussion and Conclusions

In this paper, we have presented an authoring tool for 3D virtual exhibitions and walkthroughs that uses AI techniques and careful interaction design to make the building of virtual tours easier for a CH expert with minimal technical knowledge. The tool has been adopted in a CH project, where it has successfully allowed curators, once the 3D models had been derived from laser scanning data, to include artwork information and build virtual visits rapidly and with low effort.

The experience of CH experts with the tool has highlighted once more the importance of incorporating semantics

and metadata into the 3D models of the artworks. For example, proper semantical annotations would allow the assisted viewpoint derivation to target also specific parts or features of artworks, instead of relying on manual ways of identifying them. Another advantage could be an easier integration with information taken from CH databases: currently, the association between an artwork and the information in the database has to be manually created by adding a link to a Web page displaying the result of the proper query to the database. With respect to adding metadata, however, one of the main challenges is how to spatially reference them to parts of a 3D model [KFH09].

Additional directions for future work include experimenting with alternative ways of specifying VOIs from high-level requests, e.g. providing more sophisticated results from the assisted VOI computation. For example, in the cases where a VOI satisfying all requirements cannot be computed, instead of producing a single VOI, we could generate a viewpoint path that starts from an overview of the specified objects, and then moves to more detailed views of each single object. Finally, we plan to evaluate the tool more thoroughly using a controlled experiment where multiple teams of CH experts will be required to build virtual exhibitions starting from available 3D models.

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