Towards a versatile metadata exchange format for digital museum collections

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***Abstract*—This paper presents further extensions of the virtual museum metadata set ViMCOX (Virtual Museum and Cultural Object Exchange Format). Recent research in the field of virtual museum design illustrates issues concerned with presenting content and contextual information for heterogeneous audiences; it addresses visitors' preferences for guidance as well as their need for content-related and technical mediation during virtual museum visits. This paper describes the incorporation of the TourML metadata scheme, which allows visitors to take guided tours of a 3D virtual museum or to "wander" through the virtual rooms and to select from a range of multilingual supplementary materials. In doing so, it references the exhibition space modeling capabilities of ViMCOX as well as real museum visitors' behaviors. Furthermore, the paper presents new metadata components for extended architectural design, re-use of environmental 3D models as exhibition space and new illumination metadata elements for designing light sources that affect the exhibitions' ambient light. New user-to-object interaction patterns for navigation aids and information visualization are described such that content creators can decide how supplementary material and contextual information are accessed and presented. In addition, we present the re-use and linking of open data collections, documentation and artworks using the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH).**

I. Introduction

In three recent papers [1], [2] and [3], we described the curator software suite ViMEDEAS (Virtual Museum Exhibition Designer using an Enhanced ARCO Standard). ViMEDEAS combines authoring tools, frameworks and a metadata scheme to cover the entire design process of virtual museum planning, creation, archiving, dissemination and presentation. The metadata set ViMCOX (Virtual Museum and Cultural Object Exchange Format) [4] included in ViMEDEAS is a presentation format for 2D exhibition catalogs or tangible, fully walkable 3D virtual museums. We use the term tangible, in the narrower sense that visitors can experience exhibitions interactively, view related metadata and participate in virtual tours. ViMCOX was developed to support the hierarchical description of virtual museums and provides stylistic devices for sophisticated and lifelike exhibition design, which cannot be achieved using classic museum standards. ViMCOX describes virtual museums containing both classical and contemporary art, interactive exhibition content, assets, spatial exhibition design and outdoor areas. ViMCOX is based on international metadata standards and uses LIDO version 1.0 as its interchange and harvesting format for cultural objects [5]. The key idea is to have a common modeling language and specification for virtual museums that can be adopted by different authoring tools, operating systems, rendering software and mobile platforms to outlive fast moving technology trends and ensure content durability. Werner Schweibenz addresses relevant design principles for online exhibitions [6], [7]. He describes ways to attract new users and increase the duration of a stay. We believe that his research can be applied to 3D virtual museums. In general, plain museum documentation uses specialized terminology or vocabulary created by domain experts, and content may be complex and not intellectually accessible for the general public or heterogeneous audiences; in addition, factual knowledge does not necessarily provide required contextual information, and content creators should tailor information design and visualization to target groups, providing guidance and context [6]. Schweibenz also recommends considering of alternate presentation forms and narrative storytelling to put objects into context instead of offering just metadata and digital objects or surrogates [7]. Furthermore, virtual visitors need content-related and technical mediation to explore virtual exhibitions, and visitors prefer guided tours: "less clicking, more watching" [6]. The Rijksmuseum, for example, presents an approach for generating personalized museum tours based on user profiles and semantic content recommendations [8]. Visitors can prepare individual real museum tours using content filtering or use recommended tour sets. A mobile tour guide (PDA) helps the users navigate and locate exhibits within the real museum using 2D floor plans. Chittaro et al. present VEX-CMS, a 3D curator software for designing virtual exhibition rooms with tour logic for guided and free virtual tours that refer to real museum visitors' behavior and classifications [9], [10]. The TourML metadata scheme provides a community-agreed and application-independent approach for modeling and structuring multilingual museum tours that include the presentation of supplementary materials [11]. In a recent paper, we introduced the dynamic generation of exhibition rooms and metadata using a small set of parameters that define the order and spacing of virtual exhibition objects on the walls of a room with the shape of a regular convex polygon [12]. This approach is suitable as a user-driven content filter, but it cannot convey the nature and context of an exhibition designed by curators since our algorithm generates independent exhibition space and may alter the message perceived by the visitors [13]. Therefore, we propose the incorporation of the TourML metadata scheme into ViMCOX to allow the design of virtual 3D museum tours with reference to the exhibition-space-modeling capabilities of ViMCOX (outdoor areas, buildings, levels and rooms) and the VEX-CMS approach for the design of tour logic for free and guided tours under consideration of visitors' behavior. At this stage we are not focusing on group behavior and synchronization studies such as those described by Kuflik and Dim [14]. Allowing multilingual tour content implies that content creators need additional metadata components for the

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specification of multilingual stylistic devices used in the 3D scene, i.e., tooltips or names of doors or levels on an elevator panel and bindable viewpoints, also referred to as points of interest or camera poses. To address the design principles for content- and context-related visualization and navigation aids, we present two new point-and-click interaction modes. We propose new metadata components for extended architectural design: the re-use of environmental 3D models as exhibition space, which is a desirable feature used by curator tool and virtual exhibition builder software [15], [10], [9], [16], and new illumination metadata elements to design light sources that affect the exhibition's ambient light. In addition, we present the re-use and linking of open data collections, documentation and artworks using the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH).

II. ViMCOX

First, we will briefly introduce and summarize the basic hierarchical structure and modeling capabilities of the metadata set ViMCOX and the associated generative metadata-based modeling approach [12]. Works with history are documented using international museum standards. In comparison to classical museum standards for documentation and interchange, ViMCOX is a productive standard using other standards to refer to the original artwork and its documentation. There are different kinds of digital resources, such as digital copies, reconstructions and surrogates with different quality requirements and usage intentions, like low resolution 3D scans for presentation and high resolution models suitable for research and documentation. Documentation keeps track of the reference to the original work and rights management aspects for digital resources; thus, we are using a minimal set of LIDO to describe these relations and provide display elements for presentation purposes. Abstract key components and design subsets in ViMCOX are available as high-level elements, such as outdoor areas, buildings with floors, entrance halls, rooms with walls and exhibits, and assets. Each stylistic device has its specific properties: the geometry, for example, the room shape; the appearance of walls; extrinsic parameters when positioning exhibits; interaction patterns and behaviors, which can be applied to exhibition objects; and descriptive and administrative metadata for presentation and documentation purposes. ViMCOX supports the reconstruction of real museums and the design of fictional exhibition space. In the ViMCOX metadata set, the architectural design of exhibition rooms and entrance halls can be specified as a bounding box or as a 2D floor plan. Using the bounding box method, the room shape can be designed using three construction parameters: the room's height, length and width. The result is a rectangular boxed shape. Each wall is assigned a compass direction. The room length parameter refers to the length of the northern and southern walls, and the room width parameter describes the length of the western and eastern walls. Another approach is the use of 2D floor plan data, represented as absolute 2D position, to design custom room shapes where each wall has properties to specify the visual and geometric appearance, such as texture wrapping or the number of windows or doors. In this case, doors and windows are geometric recesses, which visitors can walk and see through. In contrast we use metaphoric connectors to link rooms, horizontally or vertically, using 3D models of doors or interactive elevators [1]. Several metaphorical concepts can be used together in hierarchical order. This concept can be compared to structural and navigational metaphors applied in parallel or sequentially [17]. Exhibits are positioned absolutely within an exhibition area or relative to (partition-)walls. Interaction patterns referring to geometric modifications can be applied to virtual objects; thus, visitors can inspect and scrutinize exhibits from different vantage points [1]. We facilitate programmatic and (semi-automatic) generation of exhibitions, interior design, exhibit distribution and room layout as well 3D content export for the rendering platforms X3D and X3Dom using ViMCOX metadata as presented in [12] and [18]. Modifications are made at an abstracted semantic and conceptual level, and changes are propagated to specific software implementations, like authoring tools or visualization frameworks using ViMCOX metadata. In general, a generative metadata-based modeling approach has the flexibility to exchange authoring software, middleware, metadata processors and visualization frameworks for platform-independent rendering, for example, in future prospects, a Collada exporter for multiuser scenarios using SecondLife. This approach also facilitates the development of a different set of authoring tools, in addition to 3D modeling software, for designing or digitizing exhibitions, for example, web-based 2D sketch tools for designing floor plans, graph-based tools for linking virtual rooms or mobile curator software for acquiring room architecture and exhibit position and scale using photogrammetry [3].

III. Virtual Tours

The current approach for designing virtual museum tours using ViMCOX, is limited to ordered lists of camera poses (viewpoints) used for tour stops, marking points of interest or exhibits in a virtual exhibition room [1]. The tour stops can be selected individually by the virtual museum visitor or be viewed as camera fly-by animation. This approach is not suitable for the design of sophisticated tours, spanning multiple rooms; tour stops can not provide additional supplementary material, like descriptive metadata, hints about available user-to-object interaction modes or alternate exhibit representations. In general, tour design should take into account art history contexts, chronological ordering of tour stops, visitor's preferences and demographic background or didactic models.

A. Related Work

The VEX-CMS authoring software for virtual 3D museums, provides virtual tour modeling capabilities [10], [9]. Tour stops are modeled as viewpoints, camera poses or view directions within the 3D scene, i.e, a camera facing an exhibit, a group of objects or some other point of interest. These tour stops can be used to display information presented in a 2D overlay with HTML markup. The VEX-CMS authoring tool enables manual positioning and automatic computation of camera poses and supports the modeling of tours as directed graphs, thus, making it possible to design multiple tours or alternate routes. Additional tour logic–conditions and constraints–for activating transitions between tour stops and stipulating how navigation modes and transitions are performed can also be defined. The VEX-CMS navigation modes are designed based on real museum visitors' behavior and classifications. Navigation modes include teleporting the virtual avatar, automatic animated transition and free navigation with optional navigation aid by drawing a visual path in the 3D scene. Conditions like enter and exit events to trigger transitions between tour stops can be defined, for instance, a mouse click on a exhibit (mouse action), approaching or leaving a viewpoint (spatial proximity) or time constraints. This behavior is designed as a state automaton, where each state is a tour stop; thus, only one tour stop can be active at a time. When the avatar enters a room, a default state or the first tour stop for that room is loaded. Another approach that is not application specific is provided by TourML, a XML metadata scheme for structuring museum tours with focus on mobile devices and tour guides [11]. While the VEX-CMS approach can be used to design free and guided tours, the TourML approach leaves the tour presentation and behavior up to the software implementation. The specification of TourML was revised in several workshops by museum associates. Tour stops can be defined multilingual, and they can include tour titles and descriptions as well as multiple assets–multimedia content, web sites or geo locations–as well as properties defining how the tour stop should be experienced. This includes custom parameters, such as, the assignment of a corresponding view template–defined in the application for presentation purposes–and settings for multimedia playback methodologies, that is, how a tour stop can be selected on mobile devices, for example, via a key code entered on the mobile device's dial pad [19]. In comparison, TourML provides metadata elements for structuring and modeling tour content with the ability to specify assets and supplementary material as well as assigning view-templates for presentation purposes and promoting application-driven tour handling. The event-driven approach of VEX-CMS has a broader focus on 3D museum applications, includes the specification of selectable viewpoints as tour stops and allows modeling of tour logic with transition conditions and constraints. Both approaches use directed acyclic graphs to connect tour stops. Table I provides a comparison and feature overview of the two approaches.

TABLE I. FEATURE OVERVIEW OF VEX-CMS AND TOURML

Feature	VEX-CMS	TourML
Multilingual	HTML	Yes
Presentation	HTML	VIEW, Assets
Re-use of tour stops	Yes	No
Activation/deactivation events	Yes (proximity, duration, click)	PropertySet
Free and guided tours	Yes	Application
Linking of VM instances	No	PropertySet
Connection as directed graph	Yes	Yes
Transitions	Path, animated, teleport	Application
Tour metadata	No	Yes
Rights management	HTML	Yes

B. Tour Design And Modeling

By combining both tour design approaches and taking into account the modeling capabilities of ViMCOX, it is possible to define a set of features: Connections between tour stops can be modeled as acyclic directed graphs, and tours can span multiple logically linked exhibition areas, such as standalone room instances, levels of a building or outdoor areas which are not necessarily directly connected. Content creators are able to design free and guided tours with presentation of supplementary and multilingual material. Viewpoints are utilized as tour stops because object groups or parts of the 3D environment that are not exclusively included as exhibit can be defined as tour stops, as proposed in [9]. If user-driven selections are desired for one-to-many connections, it is necessary to use thumbnails or screenshots in user interfaces to represent subsequent tour stops. Connections specify the order in which the tour stops will be experienced. In order to design tours spanning multiple rooms, content creators need the ability to specify the exhibition areas where the tour stops are located: *RoomID*, *OutdoorAreaID* or the *EntranceHallID* of a level of a Building. In addition, content developers will be able to bind an existing viewpoint of a room to a tour stop or use disjoint viewpoints by specifying position and orientation. The use of viewpoint references is mandatory when dynamically generating rooms [12] where room dimensions adapt to content size. TourML is licensed under Creative Commons Attribution-NoDerivs, which prohibits customization, modification and alternation. Thus, it is not possible to add new metadata elements. But the tour stop definitions in TourML have an additional *PropertySet* that allows the definition of properties and parameters to specify how the tour stop will be experienced [19]. This *PropertySet* can be adapted to store 3D and application-specific parameters as well as to define the parameters of the activation and deactivation events involved in tour stops. Parameters that describe the activation and deactivation of tour stops, such as start and stop conditions or other events, are described in [10]. Such parameters can be distance (in meter) to an exhibit, the duration of a visit as an exit condition or clicking another exhibition object, button or heads-up display (HUD) element [10]. Another approach for modelling spatial proximity to viewpoints or exhibits is the specification of a bounding box (center, dimension and rotation) that can be utilized to trigger events. In TourML, all these properties have to be specified as string. Therefore, it is mandatory to use delimiters to specify parameters as demonstrated in Listing 1.

Fig. 1. Guided tour: user interface for tour traversal and presentation

TourML does, however, have some limitations. Tour designers do not have the ability to specify transition types for tour stop connections, which may indicate paths for navigation aids, teleport the user or trigger camera animation, which are all facilitated by VEX-CMS [9]. The implementation and interpretation is up to software developers and should be user-selectable. For free walking tours, it is sufficient to specify activation and deactivation events when designing tour stops [9]. Transitions between tour stops located in the same room should be performed as animated viewpoint interpolations or as collision free camera animation [9]. For exhibition areas that are not directly connected, the teleporting metaphor can be applied. In general, transitions between tour stops should be visualized or animated and be understandable to facilitate orientation and maintain context for visitor's behalf [17]. Transitions to rooms that are directly connected could be initiated by clicking on a door or some other 3D asset which serves as a teleporter. The transition to rooms that are not directly connected can also be modeled as teleporters. However, from the user experience perspective, it is appropriate to add an additional tour stop to inform the user how the transition will occur and which exhibition area will be visited next. VEX-CMS uses textual information presented in the user interface to indicate the current and next stop and how the transition will take place. Another possible application-driven approach could be a variation of HUD elements to browse and trigger transitions; this includes buttons with pictographs that adapt their appearance; for example, a door icon might indicate that the user is about to leave the current exhibition area. The application logic needs to address the switching of navigation modes and resumption of tour stops. Guided and animated tours, which do not offer freedom of movement, can be modeled using the duration of a tour stop visit or a mouse click on a HUD element as exit events to trigger transitions. The application logic can then decide, based on available connections, which stop should be experienced next. Figure 1 presents a user interface for guided virtual museum tours with HUD elements for browsing between tour stops and presenting supplementary material. Free walking tours may only offer supplemental material when the visitor is near a tour stop location. This behavior can be modeled, for example, by using just activation and deactivation events to trigger a tour stop and the resumption of the tour, while the connections serve only as references, check lists, visit series guidelines or navigation shortcuts, such as the teleport functionality provided by user interfaces. Further limitations are that TourML models a tour as a standalone instance; thus, interconnection or re-use of tour stops in different tours is not possible. Nor is the dual representation of assets as TourML assets and ViMCOX objects; thus, tour assets are disjoint from ViMCOX objects. However, we are incorporating the top-level element *TourSet* of TourML into ViMCOX to enable referencing of TourML XML instances and modeling of tour designs in situ.

```
<tourml:Stop tourml:id="stop-6" tourml:view="AudioVideo">
    <tourml:Title xml:lang="EN">Birdsong</tourml:Title>
    <tourml:Title xml:lang="DE">Vogelgesang</tourml:Title>
    <tourml:AssetRef tourml:id="birdsong_obj-6" />
    <tourml:AssetRef tourml:id="screenshot_obj-6" tourml:usage="thumb" />
    <tourml:PropertySet>
        <tourml:Property tourml:name="ExhibitionAreaID">
            Room1
        </tourml:Property>
        <tourml:Property tourml:name="ViewpointID">
            vp_obj-6
        </tourml:Property>
        <tourml:Property tourml:name="ActivationEvent">
            PROXIMITY#object6#5.0
        </tourml:Property>
        <tourml:Property tourml:name="DeactivationEvent">
            DURATION#120.0
        </tourml:Property>
    </tourml:PropertySet>
</tourml:Stop>
```

Listing 1. Multilingual virtual museum tour stop defined in TourML

IV. 3D Exhibition And Environment Models

The ViMCOX metadata modeling capabilities have not yet addressed the modeling of the exterior architecture of a room or building. The modeling of virtual exhibition rooms is limited to custom 2D floor plans or rectangular room shapes, where each room is a self-contained standalone instance and transitions to other exhibition rooms, outdoor areas or levels of a building can only be achieved using logical transitions. Furthermore, it is not possible to design entire floors of buildings or underground galleries in a single standalone virtual room metadata instance using a custom room shape represented as 2D floor plan, since the generated 3D room geometry is a closed structure. However, there are workarounds combining concave floor plans and 3D objects–representing removable structures, such as stages, partition walls, stairs or ramps–to achieve sophisticated exhibition designs. In addition, ViMCOX's texturing and 3D modeling capabilities are limited in comparison to modern 3D authoring software or 3D scanning technologies and hardware limitations may occur when, for example, adding light sources via ViMCOX as described in section IV-B, even if deferred shading and lighting techniques are used to render larger amounts of light sources. The ViMCOX metadata set does not reproduce modern texturing techniques or shader effects to simulate lighting effects or multi texturing. Curator tool and virtual exhibition builder software, which can be found in the literature [9], [10], [15] and [16], are already using 3D models as the basis for their exhibition design. Thus, we are incorporating this common and desirable feature in the extension of ViMCOX. Version 1.2 now has the ability to reference custom designs for 3D room or building models exported from 3D authoring software. We have also been using this approach for modeling outdoor areas (Fig. 2) since ViMCOX version 1.1, in which curators can specify 3D landscape models for their spatial outdoor designs [1]. This new extension allows the use of 3D models as exhibition space as well as the dynamic addition of exhibition content like assets, viewpoints, exhibits, lights, partition walls, transitions and tours. This approach also facilitates the re-use of Replicave's exhibition room templates–entrance hall, cloak room, gallery and media room [1]–or programmatically designed rooms within ViMCOX. In order to facilitate the placement of partition walls within multistory 3D environmental models, the specification of partition walls has been extended to allow arbitrary 3D positions. Prior to this, partition walls were defined at ground-level by specifying the bottom right and left corners of the wall as 2D positions, as well as the wall's height and width. ViMCOX now uses 3D position parameter to specify the bottom construction points of a partition wall. Currently, construction points must be aligned in a horizontal plane; thus, the partition walls are always cubic, without shearing or rotations. For sophisticated removable structures, we recommend using ViMCOX object types and 3D authoring software.

Fig. 2. Generated outdoor area: Ashkenazic cemetery

A. Texturing

The modeling of large exhibition spaces where the exhibition area of a single room is 60 by 40 meters [18], has revealed that it is necessary to use tileable textures and provide content creators with the ability to specify texture wrapping and rotation parameters for the floor and ceiling textures in order to prevent texture stretching. The specification to model texture wrapping for walls, that are defined in a custom room shape have already been implemented in ViMCOX. ViMCOX 1.2, now incorporates an optional texture transform extension to specify texture wrapping and rotation when assigning wall, ceiling and floor textures to a room.

B. Lighting

Discussions with curators described in [15] pointed out that the positioning of light during the planning of real exhibitions using 3D curator software tools is not required at early design stages. But in the case of virtual museum exhibitions, artists might demand the use of colored light to influence the appearance of their artworks. The first incorporated light sources available in ViMCOX version 1.0 and 1.1 referred to stationary light installations in the form of reference able ViMCOX object types that describe actual 3D models, like lamps, lanterns, strip lights, sconces or textured planes, to simulate lighting effects. These light sources do not emit light to change the appearance of exhibits or contribute to a scene's ambient light. The new metadata set in ViMCOX version 1.2 distinguishes between two light source terminologies: 3D assets to design the appearance of light sources and the new lighting types to model illumination concepts and vary the exhibition's illumination. The new lighting types, which can be used inside rooms, are actual light sources affecting the appearance of the scene and objects. The new version of ViMCOX additionally supports directional, point and spot lighting. Lighting parameters are based on the lighting equations specified in [20] and [21]. To incorporate lighting components into the ViMCOX metadata schema definition, we used an abstract lighting type to specify basic lighting components. All usable light sources inherit from this abstract lighting type. Inherited parameters are light color, light intensity and ambient intensity. Light color and intensity parameters describe the emitted light color and brightness. The ambient intensity specifies the contribution of the emitted light to the scene's ambient light or lit objects. Directional light emanates light along parallel rays of a given directional vector and thus requires an additional parameter to specify the light direction in the form of a 3D vector. A point light is an omnidirectional light source that emanates light equally in every direction. It needs additional parameters: location, radius and an optional light drop off rate specified as attenuation. A spot light emanates a lighting cone along a given directional vector, similar to directional lights. The parameters needed to specify spot lighting are location, direction, radius, optional attenuation and parameters for specifying the width and cut of angle of the emitted lighting beam. A complete overview of parameters and light specifications can be found in [21]. Our 3D content generation framework, Replicave, supports two 3D rendering platforms, X3D and X3Dom. Figure 3 shows different visual experiences of a generated 3D scene with two light sources and scaled, translated and rotated object references. A red point light is placed between two sculptures and a green spotlight is directed onto the upper part of the left sculpture. X3D supports per-vertex lighting; as a result, the shading quality of lit objects will increase depending on the objects' polygon count. In contrast, X3Dom supports per-pixel lighting and therefore provides a different viewing experience [12]. X3Dom also facilitates the specification of shadow intensities for the described light sources [22].

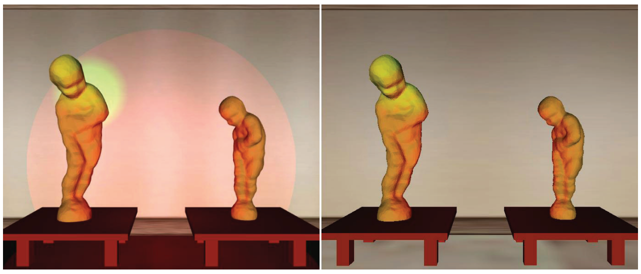

Fig. 3. Generated 3D scene with different lighting components, visualized in X3Dom (left) and X3D (right)

C. Virtual Instances

Three-dimensional positioning and arrangement of exhibits is a crucial task during exhibition design, as indicated by 3D curator tool implementations [15], [10], [23]. Therefore, ViMCOX version 1.2 simplifies the handling of virtual object instances and removable structures. Prior to ViMCOX version 1.2, the use of virtual objects in different contexts, for example, scaled or rotated instances, required manual remodeling and creation of altered 3D models. To avoid this, in addition to the current translation and positioning parameters, we propose extensions to specify scale and rotation parameters when positioning a virtual object within an exhibition. The current position parameter defines how the object instantiation and transformations are applied, whether relative to a wall–by compass-direction (rectangular room) or wall number (custom room shape)–or freely positioned with absolute coordinates. These additional parameters can be applied to all reference able objects, like exhibits, assets and thresholds, which are exhibited indoors or outdoors. Figure 3 shows two instantiations of the same 3D model with different position, scale and orientation. The specifications of ViMCOX version 1.0 and 1.1 do not facilitate modeling capabilities to select the virtual appearances of thresholds. Thresholds are connectors linking remote 3D scenes like rooms or outdoor areas. It is more convenient to use object references to support the loading of custom connectors. Therefore, we added a new attribute—the ability to specify a reference to a ViMCOX object type—thus enabling curators to select appropriate metaphoric connectors for their architectural styles and exhibition contexts or themes.

V. Multilinguality

To design multilingual virtual museums, it is not enough to have just multilingual object metadata. Some visual elements, like doors in the 3D scene that use tooltips to indicate the target of a transition or viewpoints that are selectable from user interfaces, should also have multilingual representations. LIDO, for example offers two ways of specifying multilingual content. Using repetitive language specific top-level elements or language attributes on each metadata element to type each language variant [5]. We prefer to use language attributes on our language-specific metadata elements because the complexity of changes like varying lighting, specifying user-to-object interaction modes, adding of viewpoints and thresholds or modifying the entire room shape have to be properly propagated and maintained for each language variant metadata set. The LIDO schema provides an element wrapper to record the appellations and names of entities, the *appellationComplexType*, which allows the definition of a set of appellations, such as titles, identifying phrases or entity names, where each appellation element represents a language variant [5]. We adapt this wrapper to store the multilingual appellations of viewpoints, thresholds and building levels.

VI. Point-And-Click Interaction

The new point-and-click interaction modes are used to perform actions when exhibition objects or assets are clicked via an input device, such as a single left mouse click or a single touch input. This behavior can be compared with HTML anchors and is also a common control concept used in 2D and 3D computer adventure games. With ViMCOX 1.2, we offer two new mutually exclusive interaction patterns: the point-and-click-navigation and point-and-click-presentation. These new interaction modes can be combined with the existing user-to-object interaction patterns that are indicated and performed using decoupled button panels [1], where each interaction is represented as a pictograph.

A. Presentation Behavior

Werner Schweibenz has addressed relevant design principles for online exhibitions. There are also some disadvantages when using 3D visualization as a presentation basis: the visitor's viewing angle and distance from a painting, the object's scale or less detailed textures, or the need to use polygon reduction for optimizing the performance. The main goal of this interaction mode is to let content creators decide how metadata and supplementary materials are styled and presented and how the visitor can acquire this information within the 3D scene. In real museums, the metadata for a painting positioned on a wall is accessed via a small information board, usually of postcard size, in close proximity to the painting. There are other stylistic devices, as well, such as informational plagues beside free-standing sculptures. These stylistic devices can also be applied to virtual 3D museums as shown in Figure 4. In addition, content creators can decide to make available metadata or high-resolution images or to trigger playback of an audio file when the virtual visitor performs a mouse click on an exhibit. Our new presentation approach uses application-driven view templates to manage and visualize content as proposed by TourML [11]. This interaction mode can be applied to virtual objects that can be referenced within exhibition areas. A common application scenario is the presentation of artwork metadata or disjoint content in addition to tour specific content. The metadata specification of the new interaction pattern concerning the presentation behavior consists of appellation values for multilingual tooltips used in the 3D scene as well as a *contentSet* to wrap information objects for each language variant. Each content element allows the specification of a title and description, as well as a set of remote resources with additional descriptors for rights management information to include external web sites or local files and HTML pages that are not covered by ViMCOX metadata. Our latest version provides pointers to metadata resources for presenting museum and heritage documentation as well as a set of references to digital resources (cf. section VII), for example, a list of images which could be interpreted as a slide show by an application-specific gallery view template. In addition, we offer a *propertySet* similar to TourML [19] to define autoplay, screensize and fullscreen options for referenced digital resources. The styling and arrangement of information is handled by application-specific view templates, such as XSL (Extensible Stylesheet Language) to transform LIDO metadata into corresponding HTML representations, and content creators can decide where to visualize this information, whether as 3D HUD in the 3D scene, as 2D HTML overlay, or in an external browser or frameset. Figure 4 illustrates the presentation of exhibit metadata and additional audio material with embedded media player interface. An abstract overview of how the presentation behavior is applied and how it relates to virtual ViMCOX objects and digital resources is presented in Figure 5.

Fig. 4. Information access (left) and 2D HTML overlay for presentation.

B. Point-And-Click Navigation

From user's perspective, it is beneficial to navigate to points of interest or exhibits via touch input. This feature was highlighted during the development of a kiosk system version of The Virtual Leopold Fleischhacker Museum [18], where the input peripherals of the system were limited to a touch screen and a keyboard with trackball mouse. In contrast to *LookAt* navigation modes, provided by such software as X3Dom [22]–where an arbitrary camera position relative to the selected object at a close distance is loaded–our approach binds a predefined viewpoint. The specifications of the point-and-click-navigation include multilingual appellations used as tooltips within a 3D scene, a viewpoint reference to bind and an optional attribute to specify the transition type (*animate*, *switch*). The transition type *switch* represents a direct change of the viewpoint and a smooth camera animation should be triggered when using the *animate* attribute. The key idea is to link exhibition items or assets to a viewpoint, for example, to ease the user's navigation experience and save walking time when the user is far away from an exhibition item, but still in visible range. Thus, the visitor can click on an exhibition item and will be transported to a (pre-)defined viewpoint. This interaction can also be used to link related objects by creating layered information panels with text and additional assets, like images, where each image can be linked to a specific viewpoint. This behavior can be adapted to link other rooms by defining thresholds.

VII. Virtual Objects And Digital Resources

There are ten different virtual 3D object types with tailored metadata and virtual properties available in ViMCOX 1.0 and 1.1 [4]: 2D paintings with optional frame and passe-partout sizes; sculptures and tombstones for 3D exhibit models; a 3D asset type which can be categorized into plant, light source and furniture objects; multimedia object types for audio and video files; and two 3D object types for the architectural elements window and door. The first adoption of LIDO into

ViMCOX was constrained to four display elements, to design a lightweight virtual museum standard without taking into consideration LIDO's multilingualism, and content-rich event model, as well as the lack of indexing capabilities and the disadvantage that not all LIDO metadata could be stored or visualized. The modifications presented were made to remove duplicate features and to support a generic way to access and maintain metadata in software implementations. The window and door object types were superfluous, for example, since a ViMCOX extension supports the modeling of custom room shapes using 2D floor plans, where each wall has its own properties to design geometric recesses for doors with frames and geometric windows with frames and glass panes [1]. The ViMCOX version 1.2 virtual object types are now Painting, 3D Asset and Digital Resources that describe multimedia content (audio, video, images, 3D models) representing works of art. Figure 5 provides an overview of the virtual objects, digital resources, object references and decoupled interaction pattern.

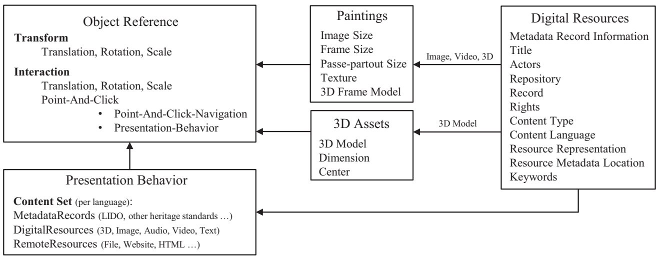

Fig. 5. Overview: Digital Resources, Virtual Objects, Object References and decoupled interaction pattern

We use the term digital resource as described in [24] to represent multiple resources of the same type, for instance, 3D models with different levels of detail or video files in different formats. To represent digital resources we utilize a subset of LIDO elements for the resource identification [5]: *TitleWrap* to identify the repository title or alternative names of the resource and *RepositoryWrap* to determine the organization that currently has custody of a physical object with a legal body name, web link and work ID, such as an inventory number and repository location. For rights management, we utilize *RightsWorkWrap* to determine the rights type, license and rights holder and to manage credit information for the original work. *RecordWrap* is used to store the website or OAI-PMH resource that describes how to access the resource online at the providing institution. We utilize multiple *resourceRepresentation* elements to document digital resource variants representing the same resource in different formats or sizes, such as thumbnails and high-resolution images. The *resourceMeasurements* elements document the technical aspects of a digital resource, such as the dimensions of a image, the bounding box of a 3D model, the duration of audio and video resources as well as bit rates and frame rates. In addition, *rightsResource* elements are required to manage divergent right holders information if a work's rights differ from those of a resource representation. We do not store other display metadata elements; therefore, we provide the ability to store a list of resource metadata locations to reference other metadata information and museum documentation. To store the creation date, creators as well as other contributors and their corresponding roles it is necessary to split up LIDO events during the import. To store additional information for indexing–geographical names or other subject terms describing the resource–we provide a keyword metadata element [24].

VIII. Metadata Interoperability

The Yale Center for British Art (YCBA) and the Rijksmuseum release high resolution images, thumbnails and metadata of their collections and artworks licensed under creative commons and public domain licenses using OAI-PMH, which is an HTTP- and XML-based protocol for publishing and harvesting. The Rijksmuseum releases metadata records as Dublin Core data sets [25], and the YCBA collection metadata is available in the LIDO format [26]. We harvested approximately 8000 LIDO metadata records with thumbnails and high resolution images from the YCBA collections "Paintings and Sculptures" and "Prints and Drawings" to create virtual museums based on query results and our generative approach [12]. We indexed the LIDO metadata records with the Apache Solr search engine. At this exploratory stage, we are only indexing the collection information, IDs, creators, dates, period, material, inscriptions and subject terms of artworks and places. The mapping of LIDO to ViMCOX is done on demand when generating the virtual exhibition spaces and the arrangement of objects is currently based on query results, such as sorting by descending retrieval score and the limitation to four exhibits per wall. We are aware of the disadvantages for laypersons in terms of query formulation and metadata complexity as described in [6]; therefore, in future versions, we intend to provide web-based interfaces to allow user driven design of virtual museums, as well as clustering techniques for exhibit distribution and floor planing.

IX. Conclusion

Museums that adapt to user models and preferences and the complexity of developing such systems has been described by Lepouras et al. [13]. The adaptive features of virtual museums comprise 3D architectural design, arrangement of exhibits and additional material on display; interaction patterns for navigation aids or user-to-object interaction modes of varying complexity; and animated objects or exhibits that can be disassembled [13]. The exhibition environment has to be created dynamically and the software needs to monitor user behavior to create adaptive tours that detect user preferences during the visit, such as preference for provided audio and video material instead of interaction patterns. We addressed the standardization for the modeling of adaptive virtual museums using content filtering, where digital artworks are arranged in a dynamically generated exhibition environment, as well as the modeling of virtual museum tours, where the exhibition context is preserved. Our metadata set provides representations for the modeling of virtual museums as a service [27] with fictional exhibition settings, digital surrogates or born digital objects and the design of fictional exhibition space, as well as reconstructions of actual physical exhibitions and museum architecture using 3D authoring software, for archiving current or past exhibitions [28]. The new utilization of 3D environmental models created with 3D authoring software facilitates the creation of sophisticated exhibition spaces with a high degree of visual quality; for example, modern shader techniques like ambient occlusion that cannot be achieved using only

ViMCOX metadata. In the case of reconstructed museums, visitors can use virtual museum tours to prepare for or excogitate museum visits. By establishing user profiles, visitors can create, persist and continue tours or share interesting tours with other visitors. In addition, we are approaching the concept of a museum without walls by André Malraux described in [29], that houses cross-collection exhibits and links additional material. Our approach also enables the creation of virtual exhibitions from digital collections and represents a step towards a learning museum as described in [29], with context-oriented and didactically enhanced material for certain user groups (demographic, knowledge) that can be modeled using interactive tours and mediated presentation forms as well as linked information. Future research will address the development of adaptive virtual museums in reference to tool sets to capture and evaluate user behavior in order to create and enrich user profiles with semantic recommendations–taking into account demographic data, content and architectural preferences, experience in 3D worlds to address navigation aids, available user-to-object interaction modes and the users' ability to learn–to generate different exhibitions, assemble different virtual museum tours and add suitable educational or supplementary material to support the virtual museum visit. It is our goal to assess our approach by comparing the user's experience as perceived in different types of museum exhibitions–actual museum exhibitions, equivalent 3D reconstructions and (semi) automatically generated museums–comprising the same content on display, with the addition of supplementary material, different visualization techniques for providing content and guidance as well as different navigation and interaction modes.

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