# Crowdsourcing and Knowledge Co-creation in Virtual Museums

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**Abstract.** This paper gives an overview on crowdsourcing practices in virtual museums. Engaged nonprofessionals and specialists support curators in creating digital 2D or 3D exhibits, exhibitions and tour planning and enhancement of metadata using the Virtual Museum and Cultural Object Exchange Format (ViMCOX). ViMCOX provides the semantic structure of exhibitions and complete museums and includes new features, such as room and outdoor design, interactions with artwork, path planning and dissemination and presentation of contents. Application examples show the impact of crowdsourcing in the Museo de Arte Contemporaneo in Santiago de Chile and in the virtual museum depicting the life and work of the Jewish sculptor Leopold Fleischhacker. A further use case is devoted to crowd-based support for restoration of high-quality 3D shapes.

**Keywords:** Crowdsourcing · co-creation · virtual museum · knowledge creation · digital 3D exhibits · standardized metadata · ViMEDEAS · ViMCOX

## 1 Introduction and Motivation

Crowdsourcing and co-creation are major players in an emerging field of research on collaborative systems. The technologies available nowadays, such as smartphones and social networks, enable people to provide and consume information in ways that were never possible before. But to what extent can these emerging technologies and changes in everyday life positively influence the fields of information systems and technology research? In this paper, we explore how crowdsourcing can be used in virtual museums (VMs) by creating and visiting virtual exhibits in various use cases. The main goal of this proposed extension of virtual museums is the enrichment of the virtual environment with information from engaged users (such as their preferred viewpoints, comments and search histories) and the generation of additional input for the curation of new museums and exhibits.

Biella [1] provides a comprehensive literature review that describes various kinds of VMs as digital heritage content, including virtual exhibits of replicated historical laboratories for the purpose of study, education and leisure. VMs and exhibits need digital reconstruction and interpretation of existing or lost artwork and their metadata, which can be deduced from existing items, photos, drawings or descriptions in books, oral tradition, expert knowledge or available metadata and recorded in a standardized metadata format. The digital representations of the artwork are then placed into a spatiotemporal context realized as indoor or outdoor exhibition space and hyperlinked to context-related information that will help visitors comprehend the digital interpretation [2]. Furthermore, through interaction with objects, displayed or spoken texts, thematic tours and electronic catalogues or tour movies, visitors can convey ideas and concepts.

In addition to the properties listed above, a VM metadata standard is also expected to support the following features [3]:

- Description of requirements concerning the presentation of exhibits and an adequate context (carrier, wall, room, lighting and so on);
- Specification of interaction methods with exhibits via adequate interfaces and reversibility to the original state after user interaction;
- Modification of exhibits with regard to position, form and content, even with the aim of creating new enhanced instances of one or more cultural objects;
- Simulation of a kind defined by a discrete or continuous process model.

In an earlier paper [2], we described the framework Replicave, developed by Biella [1] in 2006, which provides a cost-efficient way to create virtual exhibits by reusing 3D models and generating additional digital content dynamically. Its successor, Replicave2, developed by Sacher [3], uses X3D and X3DOM as rendering platforms and Java EE and the Tomcat servlet container to present exhibits online. The virtual environments can be created using customizable exhibition area templates, such as entrance halls, galleries, various media-rooms and additional interactive experiments. Replicave2 allows dynamic generation of arbitrary room designs, depending on given parameters and metadata designs specified in the VM modeling language ViMCOX. The main contribution of this paper is to present a concept that focuses on content development and enhancement realized by participatory practices and crowdsourcing, especially for Web-based museums and virtual science centers.

The paper is structured as follows. Section 2 introduces related work and focuses on the role of crowdsourcing approaches in various contexts. The discussion will show how these evolving techniques can be embedded into the creation and visiting process of VMs. Then we introduce several new approaches for the use of crowdsourcing concepts in creating (Section 3) and visiting (Section 4) VMs. Section 5 shows the feasibility of these concepts by examining three case studies. Section 6 develops a research agenda, and Section 7 discusses our conclusions and presents future work.

## 2 Related Work

Crowdsourcing on social platforms affecting social interaction is an emerging form of knowledge generation and problem solving that complements well-known practices of collaboration and co-creation. Nguyen et al. [4] define crowdsourcing as an online strategy in which an organization proposes defined task(s) to the members of the crowd via a flexible open call in order to harness their work, knowledge, skills and/or experience. They go on to provide a structured literature review, describing how to decide when to use crowdsourcing. Platforms enabling crowdsourcing offer calls to the crowd, asking for them to provide information in a meaningful way that supports the creation and use of a VM.

Many websites, including Wikipedia, Open Street Map and Second Life, illustrate important examples of crowdsourcing. We will not enter into a deep discussion about the differences between crowdsourcing and collaboration and will summarize only some of the opinions found on the web. Often, crowdsourcing and the evaluation of requested data go hand in hand with statistical evaluation. If the most probable solutions or averaging is needed, crowdsourcing seems to be a good choice since those involved work mostly independently and individually. Crowdsourcing can also bring new ideas, special knowledge and innovation into a community, whereas collaboration seeks to solve a specific problem or complete a specific task by integrating mutually complementary competences and experiences—a goal which demands qualified project management. But perhaps the best results can be achieved through a good mix of the two. As Benson [5] observes, “co-creation is a collaborative initiative which operates like crowdsourcing by seeking information and ideas from a group of people. There is, however, one crucial difference. The call for contributions is not put to an open forum or platform but to a smaller group of individuals with specialized skills and talents.”

Uden and Zipf’s [6] Volunteered Geographic Information (VGI)-based approach to 3D city modeling seems promising and expands the options for crowdsourcing 3D city models. They present a concept for a new Web platform called OpenBuildingModels, which allows the models to be linked to Open Street Map objects and displayed by a dedicated 3D viewer.

Colfi [7] provides an overview of key issues that are related to social and cooperative interactions—particularly around the design and use of technology—at heritage sites that have emerged in CSCW and that involve the conduct and the activities of visitors, the design and evaluation of interactive installations for guidance and access, and the creation of novel artistic performances and interactions with exhibits.

These areas of interest are defined in greater detail by Baloian and Zurita [8], who suggest using guidelines in the knowledge creation process that will also apply in modified form within the crowdsourcing and co-creation scenario in VMs: (a) it is necessary to consider a knowledge creation model based on crowdsourcing to organize human resources, knowledge creation and the task-completion process; (b) in complex contexts like 3D virtual environments, content and metadata creation and enhancement require crowd selection and motivation and the exploitation, validation and dissemination of knowledge; (c) knowledge creation in mobile scenarios visiting indoor and outdoor expositions demands an appropriate hardware and software platform, as well as new types of interaction support and guidance and metadata collection using current standards.

Using content produced by crowdsourcing requires an appropriate online platform that eases the transformation of 3D models and metadata into the right formats. The Virtual Museum and Cultural Object Exchange Format ViMCOX [9] has been developed in order to provide a semantic structure for exhibits and complete museums. The standard supports the hierarchical description of VMs and provides stylistic devices for sophisticated and lifelike exhibit design, interactive exhibits, assets, 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.

Simon [10] lists five stages of social participation in a VM, where each stage has something special to offer to visitors. Stage one equips them with access to the content they seek. Stage two provides an opportunity for inquiry, in which visitors can take action and ask questions. Stage three allows them to see where their interests and actions fit in the wider community of visitors to the institution. Stage four helps them connect with particular people—staff members and other visitors—who share their content and activity interests. Stage five makes the entire institution feel like a social place, full of potentially interesting, challenging, and enriching encounters with other people.

In contrast, our focus is to ask what visitors have to offer the VM during the five stages when they are accessing content, interacting with artwork, asking questions, taking their own tour and communicating with other people.

An example of this is described by Rodriguez Echavarria et al. [11]. People in local communities were invited to take photographs of the objects in the collection of public monuments and sculptures in the city of Brighton and Hove in the United Kingdom and upload them to a website along with provenance information. In this way, the same object was photographed at different times and from different perspectives, increasing the amount of data and thus helping to produce a quality 3D shape using computer vision techniques. In this way, crowdsourcing enables the generation of several 3D shapes representing the same object at different times.

Morin [12] discusses how crowdsourcing improves Web3D user navigation. User interactions are collected in order to detect meaningful elements in a 3D object and to simplify 3D navigation. Recommended views are computed and suggested to subsequent users. A similar approach is described by Nghiem [13], who proposes a new paradigm based on crowdsourcing to facilitate online 3D interactions that consists of analyzing 3D user interactions to identify regions of interest (ROIs) and generating recommendations to subsequent users. The paradigm also includes crowdsourcing activities for building semantic associations between text and 3D visualizations. The links produced are suggested to upcoming users so they can easily locate 3D visualizations associated with particular textual content.

Dallas [14] suggests a guestbook presented as a separate section of the virtual exhibition website and accessible through a link labelled “Reflections” in the permanent navigation bar of the exhibit. It is organized in sections, mirroring the internal structure of the actual exhibit, and visitors are asked to contribute to discussions by responding to a predefined question for each individual section. Admittedly, a guestbook is meant to address a public audience, not to open up interaction between communities of active participants. There are, however, some instances where visitors interact.

In Carletti et al. [15], a web survey was carried out on 36 crowdsourcing projects promoted by galleries, libraries, archives, museums and educational institutions. The authors provide classification for crowdsource tasks akin to common curator tasks (selecting, classifying, describing, maintaining) and public participation models:

- Classification—gathering descriptive metadata related to an object in a collection;
- Contextualization—adding contextual knowledge to objects;
- Collection integration/completion;
- Co-curation—using the inspiration/expertise of non-professional curators to create (web exhibitions);
- Crowdfunding—collective cooperation to support efforts initiated by others.

In conclusion, there are several proposals in the literature that support the construction and operation of VMs and exhibits by crowdsourcing; however what is missing is a complete taxonomy of such activities and a coherent architectural approach that offers tools providing feedback information from crowdsourcing to the creation process of virtual museums.

Now we want to redefine the activity of digital curation: *Digital curation* (e.g., Digital Curation Center: (http://www.dcc.ac.uk/) is the maintenance of digital research data throughout its lifecycle: re-usability of metadata, surrogates and other media or digital assets. This includes the development of digital repositories and, more importantly, the definition of guidelines and workflows for purposes such as digitization, documentation, presentation, transfer and preservation (interoperability, encoding/formats, standards, vocabularies, tool chains, services) as well as the transformation and combination of artworks to create new instances. Challenges in co-curation and digital curation include documenting provenance and applying digital rights management (DRM), for example, transfer of ownership.

Next, we focus on the generation of knowledge regarding the co-curation of museums and exhibits. The following factors are key in the crowdsourcing approach:

- There are three important stages of supporting curators in building expositions and visitors in exploring VMs through crowdsourcing:
  - Co-curating: Online creation or enhancement of digital 2/3D exhibits and contributing metadata;
  - Supporting visitors as they select and publish tours on the museum's platform, navigate in the 3D environment and interact with exhibits;
  - Discussing additional content and creating appropriate context using the electronic guestbook. Visitors are invited to use their smartphones to take photos and comment on the exhibit. This material can be used to enhance the exhibit.

- Two types of human capital are involved:
  - People in the crowd are motivated and have appropriate knowledge to contribute;
  - People working in house gather material, execute quality control and integrate exhibits and metadata into the VM using a VM metadata standard like ViMCOX and applying a DRM strategy.
- An adequate communication platform is needed, including interfaces that make collection of information and transformation to standardized datatypes accessible to the crowd.

In most cases, the artwork is copyrighted and curators are requested to adopt a high quality DRM. Thus, building and operating a VM requires the cooperation of several stakeholders. The owners of the artwork must grant permission for the creation of digital 3D representations and their dissemination via the Internet or a standalone system under certain conditions, such as watermarking the exhibit and displaying copyright information concerning limitation of use and propagation. The curator provides metadata and exposition layout, which are part of the copyright agreement. The software engineer organizes the creation of digital representations together with their metadata, installs protection and builds a VM, which is hosted on a server, kiosk system or other appropriate platform. Volunteers and visitors are invited and encouraged to contribute to the exhibition and must sign off on copyright agreements prohibiting abusive use and distribution of digital artwork.

As an alternative, leading museums abstain from watermarking and use the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH). The OAI is an organization that develops and applies technical interoperability standards that allow archives to share catalog information (metadata). It attempts to build a low-barrier interoperability framework for archives (institutional repositories) containing digital content (digital libraries) and allows people (service providers) to harvest metadata (from data providers). Open data collections such as Europeana, 3D Icons, Web Gallery of Arts and Wikipedia, together with cultural heritage institutional (OAI-PMH) repositories include metadata records, knowledge bases and corresponding interfaces for re-use of assets and artworks. The Rijksmuseum OAI application program interface collection (https://www.rijksmuseum.nl/en/api/), for example, is a set of more than 110,000 descriptions of objects (metadata) and digital images. Through suitable APIs, the museum provides a state-of-the-art service for application developers that makes collections available for use in web applications. As mentioned in [16], 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. The Rijksmuseum releases metadata records as Dublin Core data sets, and the YCBA collection metadata is available in the LIDO format. This allows the combination of artwork surrogates and sophisticated metadata elaborated by domain experts with generative VMs to let the public curate individual exhibits.

## 3 Supporting Curators through Crowdsourcing: Building Exhibits

As discussed in the introduction and literature review, crowdsourcing can have various benefits for the generation and curation of VMs and their exhibits. It can offer concepts and ideas, 3D models, metadata and work contexts. One of the most cogent arguments for crowdsourcing digital 3D models is that generating them involves high costs; with crowdsourcing, these models can be visualized and stored or exported together with appropriate textures to modern 3D printers. Similarly, an appropriate DRM can be used to combine community contributions to administrative and descriptive metadata with technical and use metadata provided by the institution.

Although high-quality 3D modeling is a task for specialists, involving engaged volunteers can help reduce costs. Volunteer involvement can be supported with software based on game consoles and open-source modeling software (e.g., low-cost 3D scanning and modeling with MS Kinect and ReconstructMe) and contribute metadata by respecting XML-based standards. However, in the museum community there are no simple solutions for both because a lot of pre- and post-processing is needed and comfortable interfaces are lacking. Generally, reconstructing software includes a viewer or editor that allows for inspecting or repairing and annotating the 3D shapes, which are afterwards stored in the exhibition repository and can be searched and selected within their local and temporal context using keywords from descriptive metadata.

Typically, one of two scanning principles is implemented: cameras or lasers moving around the object or a fixed camera setup with objects revolving on a turning table. Other image-based approaches are the Arc 3D web service (www.arc3d.be/) and the proprietary 123D Catch from Autodesk (www.123dapp.com/catch), which allows 3D digitization using modern smartphones. A comparative overview on existing models is provided in [17], which discusses multiple applications for 3D scanning, modeling and printing and provides an overview of future directions for this technology, such as 3D video capture. To create the 3D model from the image data, several software packages can be utilized to produce a triangulated surface or a mesh object and to process the color information of the object being scanned.

To mention only one system we cite MeshLab as an open source, portable, extensible system for the editing and processing, subdividing, converting, repairing and coloring of unstructured 3D triangular meshes (http://meshlab.sourceforge.net/).

The Fraunhofer IGD also provides a service for the preparation of 3D models for Web-based presentations utilizing X3DOM (http://publica.Fraunhofer.de/documents/N-264523.html). This service was tailored for the cultural heritage domain to ease the use of scanned and complex 3D models in VM applications.

Let us come back to the impact of the crowd in the generation phase. Volunteers use 1) an open source software tool for capturing 3D data from real objects using 2) an affordable 3D scanner, such as the Kinect, 3) reconstruction software that produces textured 2D or 3D models and 4) a Web-based interface for checking and transferring the model, rights and metadata. In general, the process should be completely runnable on mobile devices, especially content capture.

On the curator's side, post-processing is done by the VM staff on workstations or in a reduced form on mobile devices. An enhanced platform provides automatic post-processing facilities together with a Web-based interface for entering the 2D/3D content, metadata and copyright information.

It is important to define a versatile hardware environment to host the exhibition, for instance, a kiosk system with a modified operation mode prohibiting unauthorized user actions and an adequate user interface supporting user navigation, interaction, text input and multilingual text and speech output and logging functionalities.

Clear software requirements and standardized data formats facilitate seamless integration of contributed content. An extensive test program must include verification of software stability in accordance with the ISO/IEC/IEEE 29119 norm, stress tests for fluent navigation and display, and confirmation of complete and correct realization of the curator's content specifications and failure-free system operation over a specified time. Further recommendations are given in the next section and the use cases.

## 4 Enhancing Exhibitions through Crowdsourcing: Collaborative Knowledge Creation and Management

There are several ways to collect knowledge or information during or after a user's visit by using communication or voting tools and interaction interfaces, which may be integrated into the VM or accessed separately. Important means are input forms for entering text or formatted metadata, special purpose interfaces for interacting with the exhibit or an electronic guestbook where users can comment on the exhibit or ask questions about particular items. Typical information concerns the personal data which help to define user groups and their interests: (virtual) museums, categories of exhibits, artists and their epochs, user comments concerning the museum and exposition design, presentation of the exhibits and complementary information, quality of digital exhibit and metadata, reports of erroneous or missing information or technical flaws, system handling and usability, free navigation and guided tours, facilities to communicate with the curator, technical staff or other visitors, degree of immersion, modern multi-touch interfaces.

An example how the analysis of user input allows for adapting user interfaces is shown in [18]. Here, input is used to identify input errors through modeled error automata. These error automata can also be used to generate reconfiguration rules for formal reconfiguration of a user interface on its logical layer together with reconfiguration patterns derived from psychological guidelines. In the context of VMs, this approach can be used to identify certain visitor interaction patterns to trigger changes in the interface, the content and the exposition layout. Furthermore, other visitors can profit from this type of adaption.

In the following list, we summarize the most relevant activities in correlation with visitors' input. Most visitors' contributions concerning modifications of the exhibit and exhibition design via interaction are relevant to section 3 much as the spiral model is applied in software engineering.

- *Correcting/enhancing or completing exhibits, metadata or the technical platform.* Visitors are invited to ask questions and to provide information via various communication channels like an electronic guestbook or writing an email;
- *Identifying areas of interest.* User actions, such as approaching an exhibit, turning objects, and zooming in on certain features, are recorded and evaluated to inform further enhancement of the digitized 3D object and facilitate users' navigation in these areas, to determine user groups and navigation behavior and to assess important/interesting exhibition areas or most frequently targeted areas using heat maps that display the results of a cluster analysis. They are also used to determine which exhibition areas are less frequently visited and detect design flaws. This information can be used directly to support the curator in exhibition planning;
- *Modifying the exhibit when interaction is provided.* As described in [3], visual objects can be inspected and scrutinized from different vantage points, and the user can modify an object's position, exposition and appearance. Geometric objects can be moved or rotated, superposed, scaled or modified, cloned, or made invisible. Scene graph–based languages support the deconstruction of an object into its various parts and, in a different way, even its reconstruction from its parts. Thus, visitors become creators of various new representations of an artwork;
- *Creating appropriate context/placing objects in a context.* Visitors navigate within the exposition by moving through different viewpoints or clicking inside an exhibit area, watch metadata activating information frames, look at collections of similar items, comment on the exhibit in a virtual guestbook, make annotations, and cite related work;
- *Building their own exposition, publishing tours / storytelling / disseminating information.* As proposed in [19] as a structured task, in order to record a sequence of ideas and adapt it to the VM context, users can
  - objectify: mentally represent ideas as (an existing) pictorial artwork and their context as a museum;
  - organize: (conceive a tour) and order the pictures in the sequence required to produce a story;
  - associate and aggregate: distribute parts of the story to separate rooms or a proposed tour;
  - place or displace: hang or move each item on a wall;
  - access and enter: visit the museum (sometime later);
  - move: walk through the rooms;
  - perceive: see the items hanging on the walls, placed in the room or outside area;
  - discover: find each item along the way;
  - recognize and interpret: remember what each item represents;
- *Recommending and voting.* To elaborate valuable recommendations, information about users is needed. This information can be collected before, during or after visits.

To support the visitor or user, the VM or exhibit should be hosted on a versatile technical platform and displayed via high-performance software tools. Unfortunately, most web browser plugins that visualize virtual environments do not provide meaningful server logs or data to reconstruct visitors' tours and point-and-click navigation. A visitor moving in a HTML5/X3DOM scenario facilitates logging the position, determining proximity to an exhibit, orientation and walk direction as well as jumping to another room via a door connector or a tele-porter to produce a sort of camera replay. Also, the dwell time in front of the exhibit and clicks to access to metadata and further material can be recorded. At the entrance, during the visit or before leaving, visitors can provide information about themselves and their interests, comment or access the exhibit or parts of it. A statistical evaluation of specific user group walks makes available transition matrices, averaged dwell time and engagement. These data can help identify areas of interest (cf. list of visitors' contributions above), develop favorite tours, and publish series of pictures together with context and stories surrounding tour highlights. However, using a solution with a browser plugin requires additional effort to collect user input, record viewpoints and sojourn time, measure engagement and support tour publishing or storytelling in accordance with DRM.

One interesting question is how museum staff can encourage visitors to participate. We propose awarding participation by providing users with extra features; these might include electronic catalogues, opportunities to assess the exhibit or upload additional material, or ways to publish on the museum platform or recommend their tour. Nevertheless, which instruments are most suitable has to be further evaluated in one of our use cases.

For the first use case, which is presented in the next section, we opted for the kiosk system solution based on the European legislation that allows collection material to be made digitally available to individual members of the public through a closed network and within a special exhibition context for the purpose of research or private study [20].

## 5 Use Cases

### 5.1 The Virtual Leopold Fleischhacker Museum

The Virtual Leopold Fleischhacker Museum consists primarily of annotated photographs and reconstructed tombstones. We decided to develop the museum using X3D and Java/PHP technology and the powerful BS contact X3D plugin to display the virtual environment at http://mw2013.museumsandtheweb.com/paper/the-virtual-leopold-fleischhacker-museum/ (cf. Figure1).

Unfortunately, current X3D plugins neither support a multiuser perspective nor generate group awareness; however, an individual user may interact with the items and retrieve further information via an avatar, and Java-capable X3D browsers can be used in shared workspaces to walk, navigate and work together in complex collective tasks. It was decided by the curator that no interaction and animation should be included as stylistic devices in the free walking and guided tours.


**Fig. 1.** Welcome page of the Leopold Fleischhacker Museum with access to free and guided tours

Therefore, we will also present a digital 2D/3D object browser similar to familiar examples where visitors have the opportunity to browse and search for 2D/3D exhibit items and their corresponding metadata as well as rotating, zooming and panning the 3D reconstructions or watching predefined animations.
(cf. http://examples.x3dom.org/v-must/ipad_metadata_expert/)
Additional support for annotating objects could be implemented as well to focus on crowdsource and co-knowledge creation.


**Fig. 2.** Tombstone in the outside area

An alternative method is to use WebGL and display X3D files using X3DOM. X3DOM is developed and maintained by Fraunhofer IGD and proposes a new HTML profile that is an extension of X3D's interchange profile. However, at the start of the Fleischhacker project, tests showed that this solution performed worse than the one ultimately selected.

The virtual Fleischhacker museum hosts about 200 pictorial exhibits; 3D assets like plants, pillars, glass vitrines, benches and information tableaux; and 29 tombstones reconstructed by the crowd using photographs, Blender and X3D export and carefully placed outside in a virtual Jewish cemetery (cf. Figure 2). Several masks (cf. Figure 3) were reconstructed together with one greatly enlarged seal presented in the entrance hall of the VM (cf. Figure 4).

Most of this work was provided by volunteers and submitted online. Among others, Dr. Michael Brocke, director of the Solomon Ludwig Steinheim Institute for German-Jewish history in Essen has done significant, extensive research on Leopold Fleischhacker and allowed the museum to incorporate his archive.

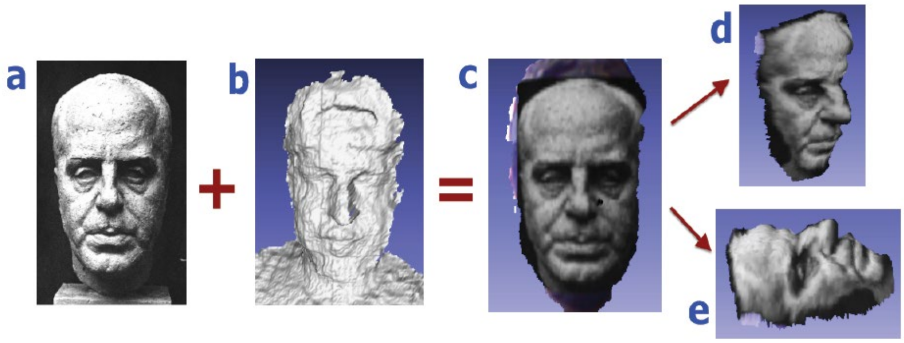


**Fig. 3.** 3D reconstruction of a mask by S. Yaslar

The exhibition design, texts and room arrangements were contributed by the curator, Dr. Barbara Kaufhold, and thematically arranged in 15 exhibition rooms in a star-shaped museum and a forest landscape. At the end of this year, the VM and selected tours will be presented in a traditional museum environment together with a few physical artworks in several displays.

**Fig. 4.** Seal and digital 3D reconstruction by S. Yaslar, 3D print out by K.-Michael Köhler
http://mw2013.museumsandtheweb.com/paper/the-virtual-leopold-fleischhacker-museum/

It has been proven that the impact of the crowd was significant and indispensable. Volunteers contributed work to the extent of about three man-years in different categories of tasks:

- Creating and enhancing digital 3D exhibits and context, mostly tombstones and medals, setup of rooms and outdoor areas, physical support for information, navigation aid etc.;
- Developing and completing the metadata standard, checking new sorts of metadata and room and landscape design;
- Defining tours, acting as test persons, and contributing to information material and catalogues.

### 5.2 Cooperation with the Museo de Arte Contemporaneo at Santiago de Chile

In January 2010 and September 2014, we digitized nine rooms presenting paintings and sculptures in permanent and temporary exhibits with the help and support of the Museo de Arte Contemporaneo (MAC) staff.

The results are partially described in [3], where we developed a new taxonomy of interactivity types inspired by certain elements of the actual learning object metadata standard LOM, such as interactivity type, intended end user role and entries measuring occupation time. Whereas geometric objects can be moved or rotated, superposed, scaled or modified, cloned, or made invisible, visual objects were inspected and scrutinized from different vantages, regions of interest annotated, and position, exposition and appearance modified.

**Fig. 5**. Animated spring experiment

Lingemann [3] has developed a framework that enables the user to manipulate objects described in a scene graph–based language like X3D via input frames and special dialogues. Configurations of an animated object and its interactive deconstruction into its various parts are recorded in X3D, correspond to the given metadata standard and can be visualized, exported or reconstituted at any time. Furthermore, the deconstruction of parts of a house consisting of cutouts of two adjacent fronts and a roof is discussed. Lingemann also implemented a virtual instance of the spring installation created by the artist Pablo Langlois in 1995 and displayed in the MAC (cf. Figure 5).

The virtual exhibit is constructed using five textured black cylinders showing human faces. At the lower end, identical springs are attached to small picture frames. The springs can be extended and animated by the visitor.

These examples show the feasibility of collecting visitors' modified artwork and user-generated animations that can be recorded and published. During the work on this use case, it was mostly volunteers who contributed to the development of a VM performance standard and to the interaction design, including implementation of prototypical realizations, such as exposition and room editors and mobile capture tools for the digitization of exposition rooms.

### 5.3 Crowd-based Support for Shape Restoration

Reconstruction of high-quality 3D shapes is a difficult problem, yet high-quality shapes are needed for scientific exploration (e.g., taking measurements of buildings and comparing details) or providing high-quality visualization results. As discussed in Section 3, existing methods of 3D crowd acquisition, like ARC3D or PHOTOSYNTH, allow 3D reconstruction from crowd-provided images. However, depending on the availability of images, the reconstructions may still be flawed, with incomplete or inaccurate geometry. While this might be improved by adding more images of the target object, the problem becomes even more severe when the original artifact has been chipped, eroded or even destroyed. Recently, a comprehensive workflow for the restoration of chipped, eroded or otherwise damaged 3D objects from the Cultural Heritage domain has been proposed [21]. This workflow comprises the following steps: (a) digitization, (b) reassembly, (c) shape completion, and (d) missing object export.

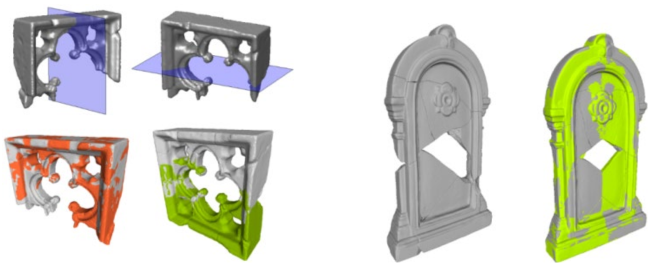

**Fig. 6.** Successful restoration of an incomplete 3D shape using automatic, symmetry-based completion (left). Symmetry-based shape completion may fail if the missing section extends across a candidate symmetry plane (e.g., the tombstone on the right).

Clearly, crowd-sourced approaches can help with (a). Fragment reassembly (b) can be done automatically if certain assumptions hold, as recent results on real Cultural Heritage object data show [21]. A problem which typically cannot be solved completely independently of application domain, or involvement of users, is the completion of missing sections of 3D shapes (step (c) in the workflow). For certain types of shapes, symmetry-based completion may be possible, and recently, robust symmetry detection in incomplete and noisy shapes has been supported using interest-point analysis [22] (see also Figure 6 left). However, for non-symmetric shapes, and shapes where the missing elements coincide with candidate symmetry planes, the method will not provide best results (see Figure

6, right). Especially in the latter cases, crowd involvement could be extremely useful in helping restore plausible, high-quality 3D shapes. Specifically, a simple Web-based query form can be designed, in which voluntary users can flag automatically created candidate reconstructions as successful or unsuccessful. In the latter case, a lightweight 3D interface could be created to allow a user to adjust the symmetry plane (if it has not been successfully detected) or to complete a missing section manually.

## 6 Recent Progress and Open Problems in the Field

In recent years, the authors and their collaborators have concentrated their research on the development of a viable VM standard, ViMCOX, in the context of existing standards like LIDO, the realization of the multipurpose system ViMEDEAS and smaller editors to design and generate virtual 3D and 2D museum environments or to publish and archive virtual exhibition layouts. The software *Mobile Object Catcher* was created to support curators and volunteers in digitizing existing museum rooms using a smartphone and its camera to measure the room photogrammetrically, to reconstruct doors, windows and walls along with the exhibit and to generate the corresponding ViMCOX metadata [23]. This also includes various ways to design and realize outdoor areas with typical landscape characteristics. Furthermore, the authors have developed an application for use by the 3D museum designer as a management tool for editing 3D objects within a graphical user interface, including real-time adjustment of their size, location and orientation as well as the creation of 3D light sources for the scene; this information can be saved in a standardized document file format. Allahbakhsh et al. [24] and Wienecke's PhD thesis [25] show evidence that a substantial effort remains to be done in automatizing the process chain to request, collect, assess and integrate crowd contributions to virtual museums.

Figure 7 summarizes the various tasks and roles within the co-curation process. This process starts by first preparing, then visiting the exhibit and, finally, identifying already completed work and important issues yet to be dealt with. The main challenges in this process include the automatic generation of

- a specific call defining the task, the qualifications necessary to address the task, and the provision of input sheets to collect text, data and metadata along with an object to be uploaded.
- access to special purpose digitizing and modeling software and communication facilities (e.g., chats) where questions may be asked or comments collected and saved.

On the software engineers' side, one needs tools to control, correct and integrate the content created. These tools include the following:

- Special similarity criteria to rate object fidelity and the means to clarify its provenance
- Metadata that meets the standards
- Decision support about the use and integration of crowd contributions

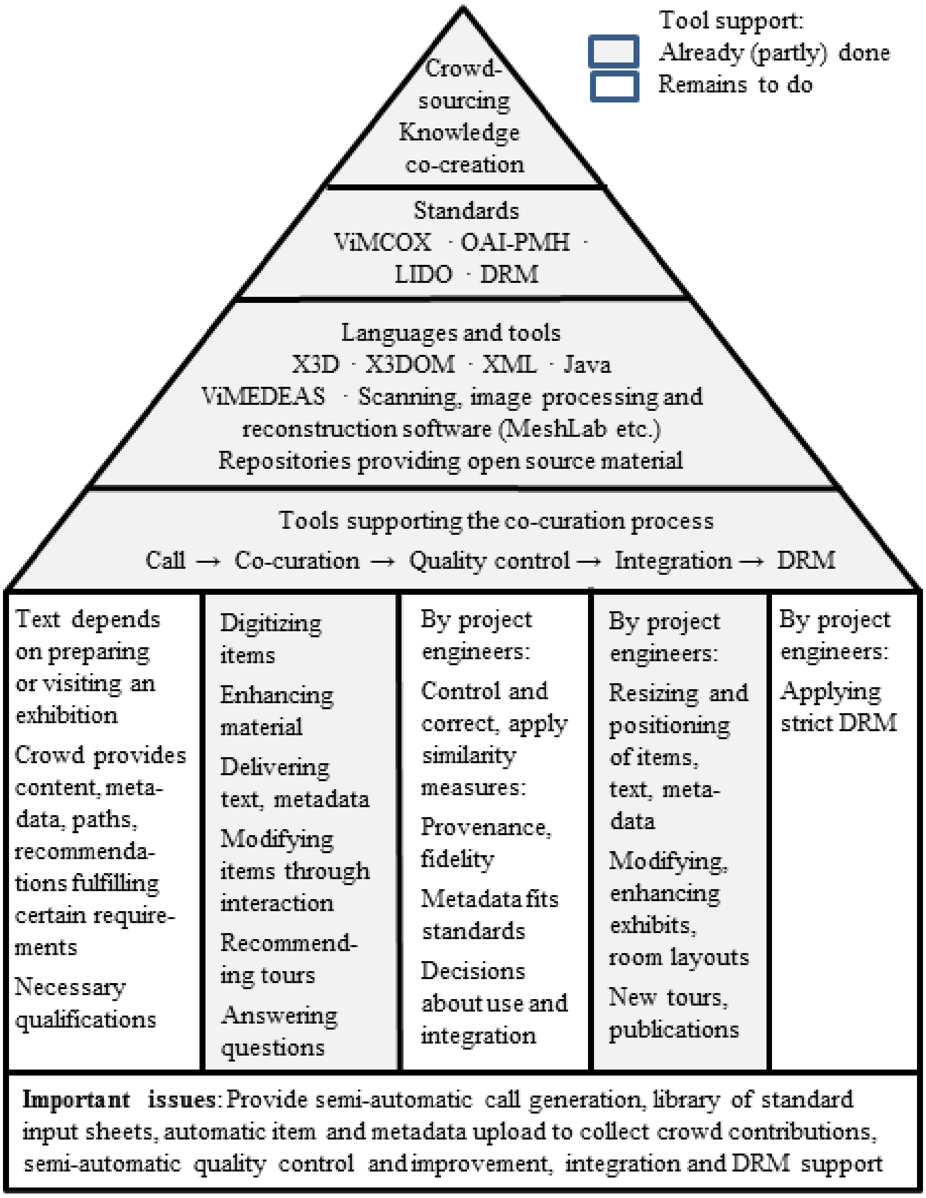


**Fig.7.** Crowd’s co-curation process chain – important issues

## 7 Outlook and Current Work

Aspects of the second main focus in our research on crowdsourcing support will be examined during an exhibition of Fleischhacker’s estate to take place at the Düsseldorf Memorial to the Victims of Persecution (Mahn- und Gedenkstätte) from November 2015 to February 2016. On this occasion, we plan to enhance our curator software ViMEDEAS [9] to facilitate the collection of crowd and user data and to include communication opportunities such as an electronic guest book.

Furthermore, we propose to implement a service-oriented architecture including a server to host the user profiles and WebServices for 3D object, metadata and tour content creation and storage based on the ViMCOX standard. We also plan to implement an X3DOM render layer to display VMs on mobile platforms, including a sensor layer to gather sensor data and update the VM representation. Our X3DOM virtual museum generator already supports Android-based smartphones and Google's DIY low-cost Cardboard VR glasses, which allow users to visit and explore generated VM environments. Further effort is being made to implement a CAVE version that allows multiple users to become immersed in the virtual environment.

Finally, during the CRIWG 2015 meeting, we plan to launch a new crowdsourcing VM project devoted to the reconstruction of the Armenian ecclesiastical heritage.

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## References

1. Biella, D.: Replication of Classical Psychological Experiments in Virtual Environments. PhD-Thesis, University of Duisburg-Essen, Logos, Berlin (2006)
2. Biella, D., Luther, W.: A General Framework for Replicated Experiments in Virtual 3D Environments. Proceedings of the 4th International Conference on Web Information Systems and Technologies (WEBIST2008), Vol. 1, pp. 316-323, INSTICC Press (2008)
3. Biella, D., Luther, W., Baloian, N.: Virtual Museum Exhibition Designer Using Enhanced ARCO Standard. XXIX International Conference of the Chilean Computer Science Society (SCCC) 2010, 15-19 Nov., pp. 226-235, IEEE Press (2010)
4. Nguyen, T., Antunes, P. and Johnstone, D.: Factors Influencing the Decision to Crowdsource. 19th International Conference on Collaboration and Technology, Wellington, New Zealand, Antunes, P., Gerosa, M., A. Sylvester, A., J. Vassileva, J., and de Vreede, G. (eds.). Lecture Notes in Computer Science, vol. 8224, pp. 110-125, Springer, Heidelberg (2013) http://staff.sim.vuw.ac.nz/pedro-antunes/wp-content/uploads/criwg-13-cs.pdf
5. Benson, S.: Co-creation 101: How to Use the Crowd as an Innovation Partner to Add Value to your Brand. (Web log comment). VisionCritical. (21 October 2013) https://www.visioncritical.com/cocreation-101/
6. Uden, M. and Zipf, A.: OpenBuildingModels: Towards a Platform for Crowdsourcing Virtual 3D Cities. 7th 3D GeoInfo Conference. Quebec City, QC, Canada (2012)

7. Ciolfi, L.: The Collaborative Work of Heritage: Open Challenges for CSCW. In: Bertelsen, O, W., Ciolfi, L., Grasso, M. A., and Papadopoulos, G. A.: Proceedings of the 13th European Conference on Computer Supported Cooperative Work, pp. 83-101, Springer, London (2013)
8. Zurita, G., Baloian, N.: Mobile, Collaborative Situated Knowledge Creation for Urban Planning. Sensors 12(5), pp. 6218-6243 (2012)
9. Biella, D., Luther, W., Sacher, D.: Schema Migration into a Web-based Framework for Generating Virtual Museums and Laboratories. 18th International Conference on Virtual Systems and Multimedia (VSMM) 2012, pp. 307-314, IEEE Press, Milan (2012)
10. Simon, N.: The Participatory Museum. http://www.participatorymuseum.org/chapter1/
11. Rodriguez Echavarria, K., Theodoridou, M., Georgis Ch., Arnold, D., Doerr, M., Stork, A., Peña Serna, S.: Semantically Rich 3D Documentation for the Preservation ofb Tangible Heritage. In: Arnold, D., Kaminski, J., Niccolucci, F., and Stork, A. (Editors): The 13th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST, the Eurographics Association (2012)
12. Morin, G.: 3D Models for…. Habilitation à Diriger les Recherches in Computer Sciences. Institut National Polytechnique de Toulouse, Université de Toulouse (2014)
13. Nghiem, T.P.: Enhancing the Use of Online 3D Multimedia Content through the Analysis of User Interactions. Doctoral Thesis, INP Toulouse (2014)
14. Dallas, C.: The Presence of Visitors in Virtual Museum Exhibitions. Paper Presented to the Numérisation, Lien Social, Lectures Colloquium, University of Crete, Rethymnon, 3-4 June 2004
15. Carletti, L., McAuley, D., Price, D., Giannachi, G., Benford, S.: Digital Humanities and Crowdsourcing: An Exploration. MW2013: Museums and the Web 2013. The annual conference of Museums and the Web, April 17-20, 2013, Portland, OR, USA, http://mw2013.museumsandtheweb.com/paper/digital-humanities-and-crowdsourcing-an-exploration-4/
16. Sacher, D., Biella, D., and Luther, W.: Towards a Versatile Metadata Exchange Format for Digital Museum Collections. IEEE Proceedings 2013 Digital Heritage International Congress, 28 Oct–1 Nov 2013 Marseille, France, Vol. 2, pp. 129-136, IEEE Press (2013)
17. Straub, J. and Kerlin, S.: Development of a Large, Low-Cost, Instant 3D Scanner. Technologies Vol. 2, pp. 76-95 (2014)
18. Weyers, B., and Luther, W.: Formal Modelling and Identification of Operating Errors for Formal User Interface Reconfiguration. 7th Vienna International Conference on Mathematical Modelling (MATHMOD 2012), Vol. 7 (1), pp. 487-492, Elsevier (2012)
19. Kuhn, W. and Blumenthal, B.: Spatialization: Spatial Metaphors for User Interfaces, Tutorial CHI 96, http://www.ncgia.buffalo.edu/i21/papers/kuhn.html
20. Dierickx, B. and Tsolis, D.: Overview of Collective Licensing Models and of DRM Systems and Technologies Used for IPR Protection and Management. eContentplus (2005), www.athenaeurope.org/getFile.php?id=665
21. Gregor, R., Sipiran, I., Papaioannou, G., Schreck, T., Andreadis, A., and Mavridis, P.: Towards Automated 3D Reconstruction of Cultural Heritage Objects. Proc. EUROGRAPHICS Workshop on Graphics and Cultural Heritage, pp. 135-144, Eurographics Association (2014)
22. Sipiran, I., Gregor, R., and Schreck, T.: Approximate Symmetry Detection in Partial 3D Meshes. Computer Graphics Forum, Vol. 33 (7), pp. 131-140 (2014)
23. Hopmann, D.: Room Measurement Using Photogrammetric Methods and Mobile Phones for Exhibition Planning and Archiving. PhD thesis (in German), University of Duisburg-Essen (2013)
24. Allahbakhsh, M., Benatallah, B., Ignjatovic, A., Motahari-Nezhad, H.R., Bertino, E., Dustdar, S.: Quality Control in Crowdsourcing Systems: Issues and Directions. IEEE Internet Computing, Vol. 17 (2), pp. 76-81 (2013)
25. Wienecke, L.: An Analysis of Productive User Contributions in Digital Media Applications for Museums and Cultural Heritage. PhD Thesis. Bauhaus-University, Weimar (2010)