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Crowdsourcing and Co-curation in Virtual Museums: A Practice-driven Approach

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Abstract: This paper gives an overview on crowdsourcing and co-curation practices in virtual museums. Engaged nonprofessionals and specialists support curators in creating digital 2D or 3D exhibits, exhibitions and tour planning and in the enhancement of metadata using the Virtual Museum and Cultural Object Exchange Format (ViMCOX). ViMCOX is based on international Lightweight Information Describing Objects (LIDO) v1.0 metadata standard, 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. Various application examples show the impact of crowdsourcing, co-creation and co-curation on the digitalization of expositions in classical museums and on the creation of virtual museums. The case studies are devoted to restoring lost or damaged artwork by the German-Jewish sculptor Leopold Fleischhacker, high-quality 3D shapes and Armenian cross stones. Finally, the paper reports on an evaluation in the field of usability, user interfaces and the crowd's willingness to undertake various co-curation subtasks.

Keywords: Crowdsourcing, co-curation, virtual museum, use cases, evaluation, standardized metadata, ViMEDEAS, ViMCOX
Categories: H.5, J.5, L.1, L.3, L.6

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. In this paper, we explore how crowdsourcing and co-curation activities 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 VMs is a taxonomy of the various subtasks in digital co-curation activities provided by the crowd or by people directly involved in the project. Based on this taxonomy, it is possible to identify necessary tool support and advice by curators and software engineers.

[Biella 06] 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 as well as their metadata. The content 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. They are hyperlinked to context-related information that will help visitors comprehend the digital interpretation. Furthermore, through interaction with objects, displayed or spoken texts, thematic tours and electronic catalogues or tour movies, visitors can convey ideas and concepts. As a data format, the VM metadata standard ViMCOX was developed in order to provide a semantic structure for exhibits and complete museums [Biella 12]. It is based on international metadata standards and uses LIDO v1.0 as its interchange and harvesting format for cultural objects. Roughly speaking, ViMCOX addresses the above-mentioned features, allows work-related information to be included in the spatial and temporal context and enables the flexible, scalable generation of 3D scenes. Discussions with curators of modern museums hosting various kinds of collections, showed that a VM metadata standard is also expected to support the following features [Biella 10, 15]:

- Description of requirements concerning the presentation of exhibits and an adequate context (carrier, wall, room, lighting, outdoor area with requirements concerning environment, various types of landscapes…);
- Specification of interactive and animated construction methods via adequate interfaces, which allows visitors to modify and return items to their original state;
- Modification of exhibits with regard to position, form and content, including the creation of new, enhanced instances of one or more cultural objects;
- An interactive canvas for controlling a simulation defined by a discrete or continuous process model.

Digital curation (cf. 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 trusted digital repositories to acquire, preserve and disseminate curated data within the community. The activities still concern the definition of guidelines and workflows for purposes such as digitization, documentation, presentation, transfer and preservation, interoperability, encoding formats, standards, compliant vocabularies, tool chains, and services. These workflows also define the transformation and combination of artworks to create new instances. Challenges in digital curation include documenting provenance and applying digital rights management (DRM) and transfer of ownership, but also the detection of malicious crowdsourcing workers, especially in the context of museums dedicated to victims of crimes against humanity [Wang 14].

Using content produced by crowdsourcing or by co-curation projects requires an appropriate online platform provided by software engineers that eases the transformation of 3D models and metadata into the right formats and supports the crowd with curating tools and standard sheets for metadata following international standards. In earlier papers, we described the framework Replicave developed by [Biella 06] in 2006, which provides a cost-effective way to create virtual exhibits by reusing 3D models and generating digital content dynamically. Its successor Replicave2, developed by [Sacher 13], uses X3D and X3DOM as rendering platforms and Java EE and the Tomcat servlet container to present exhibits online. These virtual environments can be created using customizable exhibition area templates, such as entrance halls, galleries, media rooms and additional interactive experiments. Furthermore, the use of such standardized formats offer compatibility to fully immersive systems such as a CAVE [Sacher 15]. The multipurpose system ViMEDEAS allows dynamic generation and publication of arbitrary room designs and generates virtual museum environments in line with 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, which is based on the above presented technologies (cf. Figure 1).

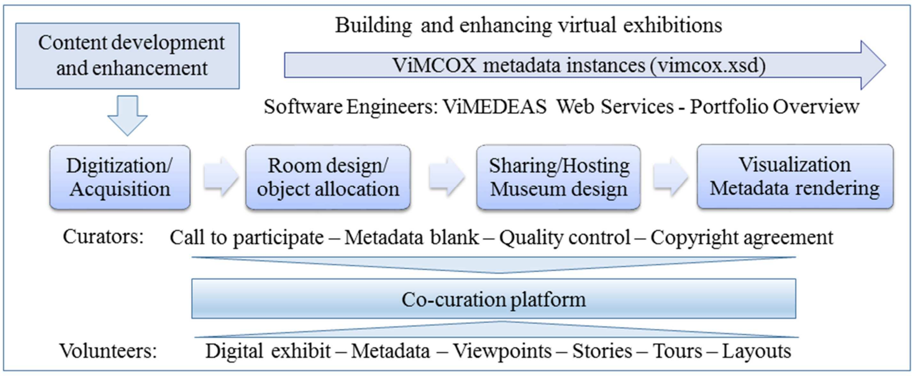

Content development and enhancement
Building and enhancing virtual exhibitions
ViMCOX metadata instances (vimcox.xsd)
Software Engineers: ViMEDEAS Web Services - Portfolio Overview
Digitization/ Acquisition
Room design/ object allocation
Sharing/Hosting Museum design
Visualization Metadata rendering
Curators: Call to participate – Metadata blank – Quality control – Copyright agreement
Co-curation platform
Volunteers: Digital exhibit – Metadata – Viewpoints – Stories – Tours – Layouts

Figure 1: Participatory co-curating approach for creating, enhancing and disseminating VMs

The paper is structured as follows. Section 2 introduces related work and focuses on the role of co-curation in Galleries, Libraries, Archives and Museums (GLAMs). Section 3 shows how participative co-curation techniques are embedded in the creation and visiting process of VMs. Section 4 reviews recent progress and open problems in the field of co-curation, and Section 5 explores case studies of various types of exhibitions. Initial evaluation results on visitors' usability issues and co-curation activities are presented in Section 6. Finally, Section 7 introduces a new participative project. This article is an updated and expanded version of our LNCS 4036 proceedings contributions to the 15th CRIWG meeting in Yerevan, Armenia, September 22–25, 2015. Additionally, we include material from [Biella 15, Sacher 15]. [Sacher 15] defines a workflow for planning, realizing, presenting and documenting real and virtual museums with the aid of domain experts, developers and users. Design decisions and workflow execution accompany a literature review, collected survey data sets, and discussions with the stakeholders involved in the development and use of virtual museums. This material also addresses these stakeholders' individual needs.

2 From Crowdsourcing to Co-curation

The term *crowdsourcing*—a portmanteau of *crowd* and *outsourcing*—was coined by Jeff Howe and Mark Robinson, who discuss it at length in [Howe 06], the *Wired* magazine article entitled 'The Rise of Crowdsourcing'. They define crowdsourcing as "the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (and generally large) network of people in the form of an open call. This can take the form of peer-production (when the job is performed collaboratively), but is also often undertaken by sole individuals. The crucial prerequisite is the use of the open call format and the large network of potential laborers."

People spend hundreds of millions of hours in crowdsourcing activities on social platforms, affecting social interaction, and on Wikipedia projects, installing new forms of content fostering, knowledge generation and problem solving, which complements familiar practices of collaboration and co-creation. It is only natural that GLAMs are exploring the potential of crowdsourcing and developing new models of participation [see Oomen and Aroyo 11]. In doing so, they identify critical challenges to the successful deployment of crowdsourcing in the digital content life cycle related to semantic web and linguistic technologies as well as to data quality.

[Ridge 13] argues that crowdsourcing projects should be "a platform for audience engagement with museums, offering truly deep and valuable connection with cultural heritage through online collaboration around shared goals". She summarizes recent experiences as contributions of the public toward a shared, significant goal or research area where achievements provide only inherent rewards for participation. She noticed a certain "discomfort of cultural heritage and academic institutions with the perceived threat of replacing digitization and research staff with volunteers". Ridge advocates design techniques drawn from casual game design and scaffolding theory by providing "clear roles and information about how to participate". Increasing participation starts with attention to content, collaborative creation of items, organization of resources for content creation and, finally, production of content with public impact.

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 various forms of collaborative works in

VM and will summarize only some of the opinions found on the web. As [Benson 13] 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.” [Adams 13] cites various contributions defining co-creation and works out similarities and differences: “Co-creation differs from crowdsourcing by the depth and richness of the relationship between the brand and participating consumers”. [Boon 11] focuses on co-creation in the history of science and technology, underlines the huge groundswell of public enthusiasm for history in general and explains: "Co-curation and similar techniques gathered together under the umbrella of ‘participation’ describe a range of practices in which lay people work to develop displays and programs within museums." [Oomen 11] lists three major models of participation also suitable as a categorization of projects designed by professionals in the cultural heritage domain: Members of the crowd contribute data in *Contributory Projects*; they contribute and analyze data, help in refining project design, or disseminate findings in *Collaborative Projects*; and they contribute and work together in *Co-created Projects*. Some participants are actively involved in more than one step in the process. An example of this is described in [Echavarria12]. 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 at different times and from different perspectives. This contributory project enables users to upload all the provenance data of the 3D shapes, such as source images, acquisition details and processing stages.

[Biella 15] cites various papers that discuss how crowdsourcing improves Web3D user navigation. 3D interactions with items are collected to identify regions of interest (ROIs), which are then used to generate recommendations for subsequent users. An electronic guestbook allows visitors to contribute information to the artwork by responding to a predefined question for each individual section. It may even open up interaction between communities of active participants.

[Carletti 13] conducted a web survey on 36 crowdsourcing projects promoted by GLAMs. The authors provide classification for crowdsourcing tasks akin to common curator tasks (selecting, classifying, describing, maintaining) and public participation models, which was proposed by Oomen and Aroyo [Oomen 11]:

- Classification—gathering descriptive metadata related to an object in a collection;
- Contextualization—telling stories or writing articles about the 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 and co-curation activities. 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.

3 Supporting Curators through Co-curation

3.1 A Classification of Co-curation Activities

Based on this observation and our own experiences, we next focus on a classification of co-curation activities for museums and exhibits. The following factors are key in the participatory approach (cf. Figure 1):

- There are three important stages in supporting curators building expositions and visitors exploring VMs through crowdsourcing and co-curation:
  - Online creation, contribution or enhancement of digital 2D/3D exhibits and its metadata;
  - Proposal and publication of tours on the museum's platform, including navigation in the 3D environment to predefined or individually specified viewpoints and interaction with exhibits to create private digital instances as defined in ViMCOX;
  - Online discussion of artwork, proposition and creation of additional content and appropriate context using a suitable platform, such as an electronic guestbook. It can be suitable to invite visitors to use their smartphones to take photos and comment on the exhibit.
- Two types of human capital are involved:
  - Volunteers are motivated and have appropriate knowledge to contribute;
  - People working in house—curators and software engineers—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 download and upload facilities that spread information to the public and collect digitized objects, metadata and copyright transfer agreements. It is also imperative that software engineers enable semi-automatic transformation to standardized datatypes and quality control.

Motivation is a further issue as is stated by [Oomen 11], [Ridge 13]: users engage in crowdsourcing for extrinsic or intrinsic motivations: for the public, these include fun, pleasure in hobbies, enjoyment in learning, competition, practicing existing skills and mastering new ones, passion for the subject and mutual recognition; for experts, it is important to attract loyal coworkers. The authors also mention two clusters of motivational factors: social connectedness and membership, sharing and generosity.

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. Volunteers and visitors are invited and encouraged to contribute to the exhibition and sign off on copyright agreements prohibiting abusive use and distribution of digital artwork. The owners of the artwork must grant permission for the creation of digital 3D representations and their dissemination under certain conditions, such as watermarking the exhibit and displaying copyright information concerning limitation of use and propagation. Curators provide metadata and exposition layouts, which are also part of the copyright agreement. They create appropriate blanks conforming to a given XML schema through which to gather artworks' metadata. Software engineers organize the creation of digital representations together with their metadata, install protection and build a VM, which is hosted on a server, kiosk system or other appropriate platform (cf. Figure 1 and the left side of Figure 8).

Leading museums abstain from watermarking and use the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH). As mentioned in [Sacher 13], 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.

3.2 Supporting Curators through Co-curation: Creating Reconstructed 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 context information. 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 by software based on game consoles and open-source modeling software (e.g., low-cost 3D scanning and modeling with MS Kinect and ReconstructMe or high quality scanning with Artec and visualization using NVIDIA Quadro stereo techniques). The workers contribute metadata by respecting XML-based standards as developed for use case 2 [see Section 5.2 below]. However, in the museum community and especially for curators and software engineers, there are no simple solutions because a great deal of pre- and post-processing is necessary and comfortable interfaces are scarce. Generally, reconstructing software includes a viewer or editor that allows users to inspect or repair and annotate the 3D shapes. The results are afterwards stored in the exhibition repository and can be searched and selected within their local and temporal context using keywords from descriptive metadata [Biella 15].

As reported in most 3D scanning forums, one of two scanning principles is typically 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 (arc3d.be/) and the proprietary 123D Catch approach from Autodesk (www.123dapp.com/catch), which allows 3D digitization using modern smartphones. A comparative overview on existing models is provided in [Straub 14], who discuss multiple applications for 3D scanning, modeling and printing and provide 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.

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. Engineers must 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, standardized data formats and the use of the Creative Commons Attribution Share Alike International License (CC BY-SA 4.0, https://creativecommons.org/licenses/) approved for free cultural work to share original works of authorship and other content facilitate seamless integration of contributed content.

3.3 Enhancing Exhibitions through Co-curation: Collaborative Knowledge Creation and Management

There are several ways to collect knowledge or information during or after a user's visit through 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 and electronic guestbook where users can comment on the exhibit or ask questions about particular items. Typical information concerns the personal data that help define user groups and their interests: (virtual) museums, categories of exhibits, and artists and their epochs. User comments tend to concern 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. They address free navigation and guided tours, facilities for communicating with the curator, technical staff or other visitors and means of interaction, degree of immersion, and modern interfaces, such as multi-touch tables.

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 3.2 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, such as completing questionnaires, signing electronic guest books or writing emails;

- *Identifying areas of interest to support the curator in exhibition planning.*

User actions, such as approaching an exhibit, turning objects and zooming in on certain features, are recorded and evaluated. This provides information about further enhancement of the digitized 3D object and users' navigation in these areas, helps determine user groups and navigation behavior and enables assessment of interesting exhibition areas or 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 to detect design flaws;

- *Modifying the exhibit when interaction is provided.*

As described in [Biella 10], visual objects can be inspected and scrutinized from various 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 multiple 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.*

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 an 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 teleporter to produce a sort of camera replay. Also, dwell time in front of the exhibit and clicks performed to access metadata and other 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 entire exhibit or parts of it. A statistical evaluation of specific user group walks makes available transition matrices, average 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. Which instruments are most suitable will be further evaluated in one of our use cases.

For the second use case, which is presented in the next section, we opted for the kiosk system solution, which supports free exploration and guided tours based on the European legislation, which 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 [Dierickx 05].

4 Supporting Co-curation: Recent Progress and Open Problems

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 such as LIDO, the realization of the multipurpose system ViMEDEAS and smaller editors to design and generate virtual 3D and 2D museum environments and to publish and archive virtual exhibition layouts.

On the digitizing side, one area that must be addressed is existing exhibitions with paintings and 3D artifacts to be scanned. [Hopmann 13] has created a software Mobile Object Catcher to support curators and volunteers in digitizing existing museum rooms using a camera to measure the room photogrammetrically; it runs on a smartphone with either an Android or a Windows Phone operating system. The tool records a complete room design and creates metadata in the ViMCOX standard (<vimcox:rooms>, <vimcox:objects>) in order to reconstruct the room in X3D language using photos, including its windows, doors and other items as well as their sizes and positions. The user furnishes the width of a wall and the wall angles. Finally, the metadata file is saved and can be sent by mail to another user. The tool was developed with the open source developer tool *PhoneGap*, which allows cross-platform solutions. The precision strongly depends on the screen resolution and guarantees an absolute error of ±0.6%. [Yaslar 13] describes a workflow to reconstruct 3D masks by using photographs as texture for a 3D model reproduced from scanner data (i.e. MS Kinect as a head scanner) and using *Blender* reconstruction software.

Our approach also includes various ways to design and realize outdoor areas with typical landscape characteristics. Furthermore, we 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 and the creation of 3D light sources for the scene. This information can be saved in a standardized document file format.

To summarize, the co-curation 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;
- an access to special purpose digitizing and modeling software and communication facilities (e.g., chats with the curator, experts, software engineers), 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 features:

- 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.

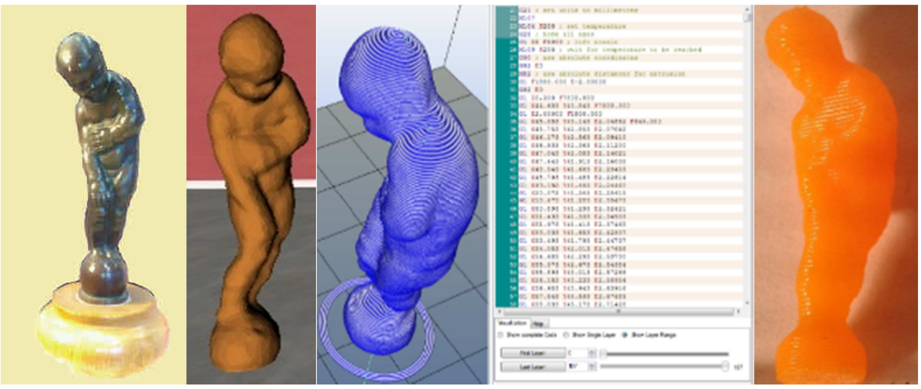


Figure 2: Seal and digital 3D reconstruction by [Yaslar 13], 3D printout by [Köhler 14]

[Köhler 14] produced a 3D printout of the reconstructed seal placed in the middle of the access hall of a VM presenting the work of Leopold Fleischhacker (LFM) and describes the workflow as follows: 1) provide the geometrical data, 2) preprocess data and execute machine setup, 3) slice the object and generate a path of the printer head and 4) build and post-process the output. On Figure 2, photos and screenshots illustrate the steps in the process. From left to right these are (1) scan the sculpture, (2) produce a Blender model followed by (3) toolpath visualization and (4) use *Slic3r* to convert the digital 3D model into printing instructions, such as G code. This process cuts the model into horizontal slices, generates toolpaths to fill them and calculates the amount of material to be extruded. The final result can be seen in the rightmost image.

We conclude this section with some brief remarks about the experiences in our co-curation projects: Engaged and motivated people did a great part of work; curators and software engineers furnished a concept, allowed access to the artwork, introduced the ViMCOX standard and provided tools. A clear definition of the workflow and the requested contributions, support during realization, and quality control are also important; rights transfers and water marking techniques were also agreed.

5 Use Cases

This section demonstrates the relevance of co-curation and crowd-sourced information by means of two use cases. Section 5.1 examines semi-automatic shape restoration supported by crowd editing, and section 5.2 explores LFM embedded in a physical museum offering various channels for visitor interaction and feedback.

5.1 Semi-automatic Shape Restoration Based on Shape Completion and Crowd Editing

Reconstruction of high-quality 3D shapes is a requirement for appealing, authentic visual presentation in virtual museums, but also for distributed scientific exploration.

For example, archaeologists might wish to take and compare measurements of exhibit items. As discussed in Section 3.2, existing methods of 3D crowd acquisition, such as ARC3D or PHOTOSYNTH, allow 3D reconstruction from crowd-provided images. However, depending on the availability of images, these reconstructions may reveal incomplete or inaccurate geometry. While this might be improved for intact items by adding more images, the problem persists when the original artifact has been chipped, eroded or partially destroyed. Recently, as part of the EU project PRESIOUS we proposed a workflow for the restoration of 3D objects in the Cultural Heritage domain starting from fragmented and possibly eroded items [Gregor 14, www.presious.eu].

This workflow comprises the steps (a) digitization of fragments or whole items, (b) fragment reassembly, (c) shape completion, and (d) object finishing. Clearly, crowd-sourced approaches can help with (a). Fragment reassembly (b) can be done automatically if certain assumptions hold, for instance, robust detection and matching of fracture surfaces [Gregor 14]. For shape completion (c), in some cases self-similarity or symmetry properties can be exploited. Specifically, local 3D feature analysis can support symmetry detection in incomplete and possibly noisy shapes [Siripan 14] and be used to complete missing local details or larger parts of a shape (see Figure 3 left to center). However, this method may fail in a number of cases involving non-symmetric shapes, symmetry ambiguity, missing parts and so forth, which extend across symmetry planes (see Figure 3, right). Then, crowd-based approaches can be valuable in several ways. In the case of ambiguous symmetries, one can imagine a voting scheme where users collectively identify the most plausible restoration result from a list of automatically suggested candidate shapes.

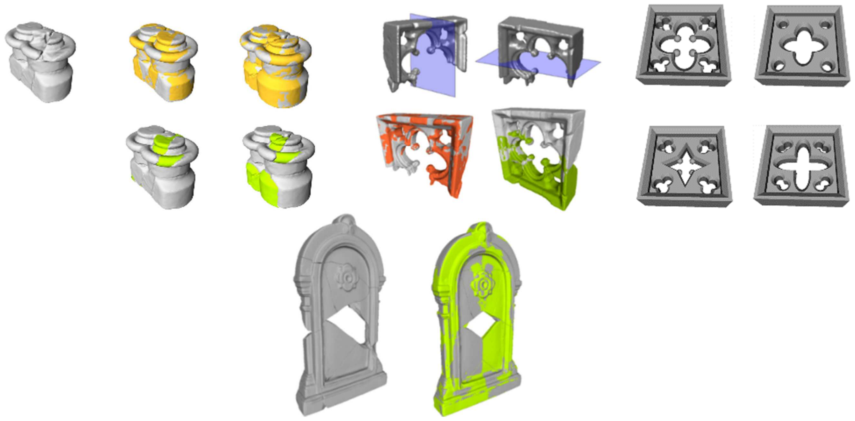


Figure 3: Successful restoration of incomplete 3D shapes of a column base (left) and an arc (center-left), using fully automatic symmetry-based completion. Parametric shape templates of relevant objects (center-right) may be helpful for completing objects when symmetry analysis fails due to missing geometry across symmetry planes (tombstone, right).

Another option is interactive editing of missing parts. An interesting and potentially scalable approach includes the modeling of parametric template shapes describing a set of plausible shapes in the domain of the virtual museum (see Figure

3, center-right, for an example). The system may use such template shapes in several ways, including as validation of automatically computed restoration results or as a reference for interactive shape completion. Crowd-based approaches could also be helpful in finishing a restored shape with respect to object surface detail. Approaches such as GeoBrush [Takayama 14] can help to finish the surface details of restored object parts by interactively transferring surface details from original to restored parts. In future work we wish to explore the latter ideas further.

5.2 The Virtual Leopold Fleischhacker Museum

The LFM consists primarily of annotated photographs and reconstructed tombstones and hosts about 200 pictorial exhibits in 13 rooms; 3D assets include plants, pillars, glass vitrines, benches and information tableaux. 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://www.vimedeas.com/museums/MuseumPHP/.

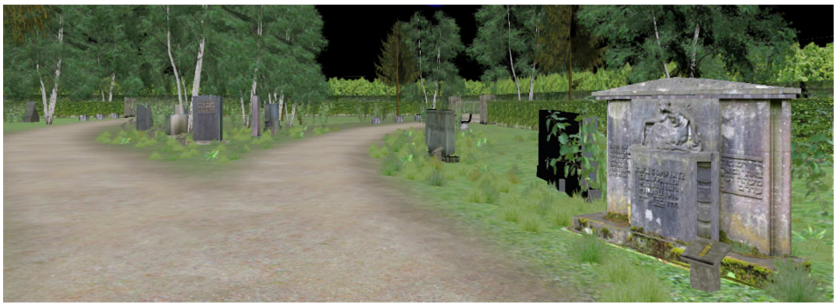
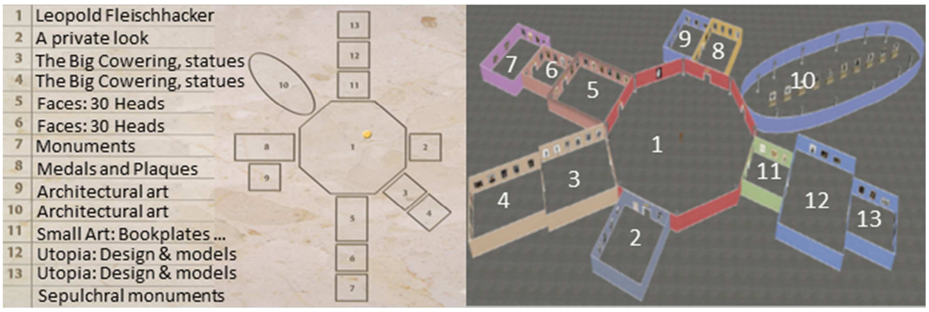


Figure 4: Tombstones in the outside area (Foreground: Rosa Gompertz [Karnuth 23])

Twenty-nine tombstones were reconstructed by the crowd using photographs, Blender and X3D export and carefully placed outside in a virtual Jewish cemetery (see Figures 4 and 5). Several masks were reconstructed together with one greatly enlarged seal presented in the entrance hall (see Figure 2).


1 Leopold Fleischhacker
2 A private look
3 The Big Cowering, statues
4 The Big Cowering, statues
5 Faces: 30 Heads
6 Faces: 30 Heads
7 Monuments
8 Medals and Plaques
9 Architectural art
10 Architectural art
11 Small Art: Bookplates ...
12 Utopia: Design & models
13 Utopia: Design & models
Sepulchral monuments
1
2
3
4
5
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13

Figure 5: Room layout of the kiosk version and as bird eye's view of the LF as it has been deployed on the aixCAVE at RWTH Aachen. All rooms are arranged around a central room, which enables access to the various exhibitions (see [Sacher 15]).

It has been proven that the impact of co-curating 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 and so forth;
- 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.

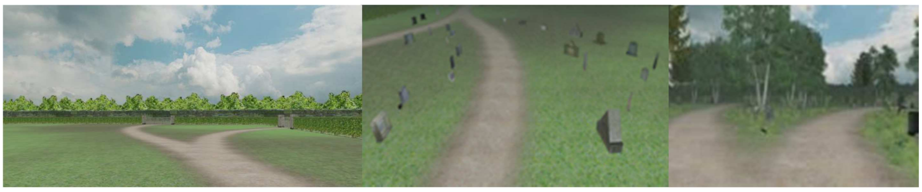

Figure 6: Several stages of terrain creation with optional objects

The software engineers (here a group of CS students) furnished a terrain generator (see Figure 6). To build a landscape involves the following steps:

- Create all resources, height and density maps. Define object parameters;
- Launch the generation process: Input object data and metadata—creating the terrain and placing the objects level by level;
- Output the complete X3D file, completing a terrain pass and object pass.
- Manually modify the X3D program to initiate a complete outdoor generation process;
- Add items (exhibit) and specify position, scale and direction.

The generation process applies multi-texturing and texture blending to create a realistic landscape consisting of several terrain layers, which may override each other. First, a basic terrain is created using a height map. Then comes a surface in green tones and a path guiding the visitor to the artwork. Next, a fence, a skyline with borders, tree lines or grass planes, fog and directional light can be added, as can objects such as markers or seats. Finally, a natural background and skyline are created. Once a terrain has been generated, tombstones or other objects are aligned along the path or in the field. Access to a database with metadata and information on items is possible via a head-up display. Clicking on an information button initiates transformation of metadata to HTML code, and the plugin opens a window displaying the text.

6 Evaluation Design, Exhibition Realization and User Questioning during the Fleischhacker Exhibition in Düsseldorf

Evaluation aspects can be considered from the vantage points of curators, software engineers, the general public and researchers involved in the development and use of virtual museums with a focus on their individual needs. To structure our approach, the evaluation is described in analogy to the framework presented in [Antunes 2012].

Prior to the start of the project, a preliminary questionnaire was developed within a knowledge-based evaluation setting. Partitioned into five parts, it helped identify goals for all the parties involved and gather relevant information about the collections, digitization, metadata techniques and interoperability standards to be used in the field as well as possible usage scenarios for creating VM curator tools.

After realization of a prototypical LFM, a further knowledge- and rule-based evaluation dealt with software stability in accordance with either the ISO/IEC 9126 or the ISO/IEC/IEEE 29119 norm, failure-free system operation over a specified time, stress tests for fluent navigation and display, and confirmation of complete and correct realization of the curator’s content specifications. Another survey designed as an interview with targeted questions provided two use cases including free and guided navigation through the exhibition rooms and outdoor area exhibition. It focused on design flaws, subjective increase of knowledge, overall acceptance of virtual museums and visual fidelity/quality. A heterogeneous observation group was interviewed to gather feedback from information technology and virtual reality specialists, art history experts, average museum visitors and computer-savvy users from the University of Duisburg-Essen, the Steinheim Institute and the RWTH Aachen.

The usability concept, co-curation contributions by the crowd and support by curators and software engineers were examined during an exhibition of Fleischhacker’s estate at the Düsseldorf Memorial to the Victims of Persecution from November 10, 2015, to January 27, 2016. The initial room layout (see Figure 5) was designed for an on-site kiosk system with touch-screen input. Moving to the next viewpoint, visitors selected the nearest object or changed rooms in the virtual museum using point-and-click operations or well-known metaphors. Based on the LFM metadata, Replicave2 generated a content bundle and a VRML file, which was passed to *Inside*, an extension of the ViSTA toolkit for interactive rendering in a CAVE. In this more interactive environment, the visitors virtually walk through the virtual museum. Visitors are able to access supplementary material or comment/annotate exhibits by photographing Quick Response (QR) codes placed in direct proximity to each exhibit item.

In the new Julo-Levin hall, four terminals were installed with four different versions of the LFM. In addition to the version with gamepad and overhead projection, on the left side of the room, there was a kiosk with touch screen, track ball and reduced keyboard to support point-and-click operations and protect the browser and operating system against manipulation, allowing free exploration and guided tours through the exposition. Additionally, two modern all-in-one screens on the other side of the room ran Windows 8.1 in kiosk mode configured for assigned access to selected apps in full screen mode. This kept the system secure and prevented users from accessing other applications or components of the operating system in the

Windows desktop environment. To navigate, users employed familiar touch screen gestures such as tapping, pressing, sliding, swiping and rotating. Seven video tours were available, in addition to the version already used on the kiosk system. (See Figures 7 & 8.)

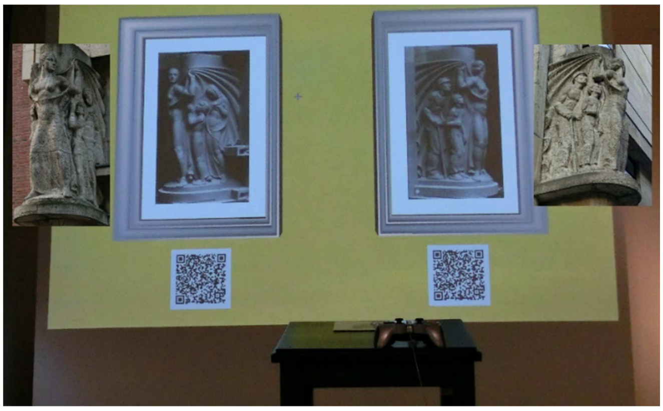

Figure 7: Interactive version with gamepad and QR code: the Madonna of the Protective Cloak *together with photos of the original sculpture. This architectural sculpture adorns the offices of the health insurance company AOK in Düsseldorf Kasernenstrasse. This larger-than-life figure is reminiscent of the Christian images of the Madonna of Mercy. Symbolizing the protection offered by the insurance company, on one side, she shelters a pregnant woman with a child in her cloak and, on the other, a wounded worker and an old man.*

In our approach to VMs, crowd-sourced support in building virtual exhibitions is closely linked to the means to navigate and access items and the metadata they provide for visitors. Therefore, a summative evaluation of the system focused on usability issues and co-curating activities as distinguishing features. For this final study we designed an initial questionnaire with 27 closed questions and a final comment field for visitors working with four versions of the LFM, each of which proposed a different way to navigate through the exposition areas and various degrees of interaction. Twenty-five visitors aged 16 to 79 volunteered to participate in our study. An initial, “younger” group (aged 16 to 18, with two or four years of computer science instruction) was drawn from a course entitled Computer Science and Society: Virtualization in Everyday Life at Horkesgath High School in Krefeld. These students had just been introduced to their first 3D modeling approaches and X3D language in class; prior to that, they had used virtual environments mainly in a gaming context. The second, “older” group consisted of visitors to the LFM who were willing to complete our questionnaire.

Both groups were introduced to the exposition and to the use of hardware installations partly through written material—a flyer and two tutorial pages just after the introductory screen—and partly through instruction—the younger group by the accompanying teacher and the main author of the paper. They were introduced to four available hardware installations: a kiosk with a touch screen, trackball or special keys for navigation; point-and-click operations for selecting and approaching items; two modern all-in-one touch screen computers; and a wand projection with a gamepad for walking through the exposition area.

Several tools were used to evaluate the questionnaire. The test persons' data (age) and answers were transferred to an Excel spreadsheet and analyzed with the statistics software SPSS, displaying various kinds of diagrams and applying appropriate hypothesis tests, like the Mann-Whitney U-test. As qualitative feedback from the usability questionnaire, 18 participants stated what they liked the most and the least and what they would like to change. The 17 positive responses mainly concerned the wall projection with the gamepad, which enabled visitors to virtually walk through the rooms and to approach and explore the items, creating a kind of gaming atmosphere.

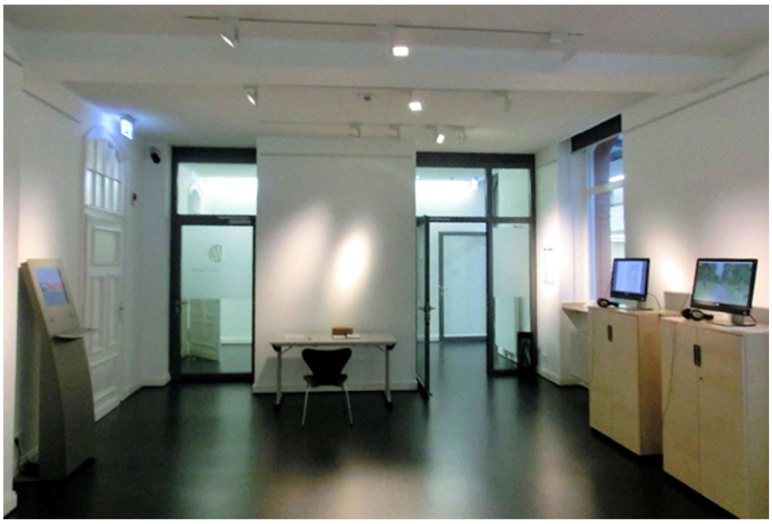

Figure 8: Virtual Fleischhacker exhibition with kiosk and touchscreens in Düsseldorf

A few people mentioned interesting, well-presented content and the electronic catalogues. Without being explicitly asked, participants consistently tried out one or more tours (nearly three of five), but favored free exploration especially with the wall projection and gamepad navigation, it looks "like a game" and eases "the access to further information". Three persons disliked the use of QR codes. Comparing the two kinds of free exploration on the kiosk and the touchscreen, most people preferred working with a modern touchscreen and found the kiosk touchscreen too slow and the navigation too cumbersome. Some criticized interface aspects such as missing seats or headsets, frozen screens and the absence of real artworks.

Then, we compared the responses of the younger group (n_1=12) with those of the older group (n_2=13).

Questions concerning the wall projection and gamepad navigation

25	I had no problems navigating using the gamepads.
26	I liked the presentation via wall projection.
27	I liked moving through the exhibition space using the projection.

The hypotheses for the comparison were as follows:

H_o: *The two samples come from identical populations; the results of both tests are indistinguishable.*

H_1: *The two samples come from different populations.*

We transformed the samples into a ranked list, calculated the sum of the rankings (T_1=105, T_2=220), the test variables U_1=129, U_2= 27, U:=min(U_1,U_2), and the ratio z = (U- μ_U)/σ_U.= (27-78)/(13√2) =-2.77. This value was compared to a table of critical values (here -1.96) for z based on the sample size of each group. z exceeded the critical value at a significance level of 0.05, which means that there was evidence for rejecting the null hypothesis in favor of the alternative hypothesis.

Questions concerning the kiosk using a five-point Likert scale (5: completely agree)

No.	Median (Mdn), Mean value (MV), Range (r), Variance (Var)	Mdn	r	MV	Var
14	I was able to orient myself in the museum.	5	2–5	4.32	0.89
15	I could approach the artworks.	5	1–5	4.48	1.08
16	I had no problems moving between the rooms.	4	3–5	4	0.48
17	I had no problems reading the information about the artworks.	4	1–5	3.77	1.80
18	I could listen to the audio files.	4	2–5	4	1
19	I liked the free exploration.	5	2–5	4.36	0.72
20	I could navigate easily within the museum.	4	2–5	3.74	0.75
21	I liked the indoor area of the museum.	4	1–5	3.65	1.42
22	I liked the outdoor area of the museum.	5	2–5	4.19	1.16
23	All in all, I like the virtual exposition	4	2–5	4.17	0.70
	Questions concerning the wall projection				
25	I had no problems using the gamepads to navigate.	5	1–5	4.125	1.85
26	I liked the wall projection presentation.	5	1–5	4.125	1.59
27	I liked moving through the exhibition space using the projection.	5	3–5	4.5	0.64

Our first questionnaire, which included with the topic “Correcting/enhancing or completing exhibits, metadata or the technical platform” indicated that

- the visitors had clear preferences concerning the technical platform and the means of navigation, exploration and interaction with the artwork;
- there was a significant difference between the group of daily visitors with average age 50 and the school class concerning the use of gamepads and QR codes and concerning exploration via wall projection or touchscreen PCs; from this, we concluded that we need virtual museums that offer a variety of hardware platforms and interaction styles;
- only a few hints were offered on further artwork to be included or metadata to be completed and only a small minority (20%) wanted to download the catalogs.

Another questionnaire with 18 items concerned co-curation activities for the LFM and was distributed to the student group. We wanted to know, firstly, whether the taxonomy of proposed activities was meaningful and, secondly, which of the relevant activities would be chosen or discarded by a particular visitor group. Nine questions were devoted to the group’s participation during preparation of a virtual exposition, that is, the production of digitized items and contributions to the related metadata; six items concerned contributions to the ongoing exposition and publication of a tour, viewpoints or information about the artwork; and the last three questions pertained to users' potential need for support from curators and software engineers.

	Five question were mostly answered Yes	Yes
4	I took a photo of the *Madonna of the Protective Cloak* in Düsseldorf.	11/14
8	I would like to propose solutions for frames, wall color and room lighting.	9/12
9	…. contribute metadata concerning the genesis and history of the artwork.	11/14
13	…. to propose special views or viewpoints about the items, magnifications or details.	11/14
16	I needed support from curators and software engineers and special purpose hard- and software to digitize and generate items.	11/13
	Two options were rejected by more than 77%	No
5	… to gather interesting information on artwork similar to the *Madonna of the Protective Cloak* on the Web and enter data in prepared internet forms.	2/14
10	… to propose special tours in the virtual museum.	3/14

The students' participation during preparation of a virtual exposition—production of digitized items, design of their environment and contributions to metadata, special views and areas of interest—were clearly approved. In contrast, providing new tours or information about the artwork was rejected by the majority. However, support from curators and provision of special purpose hardware and tools by software engineers were highly appreciated.

7 Outlook and Further Work

Even if this evaluation survey delivers only preliminary results, we concluded that it is expedient to include concise questions concerning various subtasks in co-curation activities within a call to build a virtual exposition and that there is a sufficient acceptance to support curators in preparing expositions of general interest.

It was decided by the curator of the LFM that no interaction or animation should be included as stylistic devices in the free walking and guided tours. Therefore, we will also present a digital 2D/3D object browser similar to familiar examples (cf. http://examples.x3dom.org/v-must/ipad_metadata_expert/) 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. Further work concerns evaluation software for museum designer to determine points of interest, visualizing user walkthroughs including interaction behavior, duration of a visit and tracks. Additional support for annotating objects could also be implemented to focus on crowdsource and co-knowledge creation.

During the CRIWG 2015 meeting, we considered launching a new crowdsourcing VM project DiKEViMA devoted to Armenian *khachkars* (cross-stones). We wanted to identify accessible *khachkars* based on a classification of style and époque to create digital 3D models using photographs and open-source reconstruction software. We decided to recruit people with some experience in the area via an open call to students at the American University of Armenia in Yerevan and the University of Chile and to create an upload site for X3D models, metadata and copyright transfer; we also provided tools for and advice on producing high-quality 3D models, their surroundings and relevant metadata in standardized formats. To this end, we put together a team of eminent specialists in several countries who provide us with data, context information and photographs to find the most interesting specimens for virtual *khachkar* fields and the reconstruction of an important part of Armenian ecclesiastical heritage (http://www.vimedeas.com/wordpress/?page_id=203).

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