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1. Executive summary

WP4 aims at identifying a service platform with its infrastructural components to be used by V-MusT.net partners and in the future to be expanded, adapted and used by a broader VM community.

The first activity and deliverable planned in WP4 concerns the analysis of the users needs in terms of platform components and functional specifications (leader: CNR). This includes a scouting activity for the individuation of relevant available components (other EU projects, Open Source software tools, outstanding proprietary service and/or technologies) to be incorporated in the service platform, their related technical characteristics, their architectural models at project time.

The result of this activity is the current report, that presents available technologies and tools for the assessment of the design of the V-MUST platform (deliverable 4.2).

The work for selecting the set of components was based on previous discussions of the V-MUST partners (e.g. meetings, House of Questions) and on a suitable and extensive technical questionnaire, designed to gather full information about available tools and experiences from people involved in the development of Virtual Museums at different level (e.g. curators, museums or temporary expositions management staff, software developer, researchers).

2. Introduction

This document presents the initial analysis and the specifications of the components of the V-MUST platform, developed in the framework of Work Package 4. After previous discussions and studies made by the V-MUST partners (through House of Questions, technical meetings, output of other WPs) a first definition of the V-MUST Platform has been built. This initial design (see Figure 1) will be further specified and integrated later. The final specification and the implementation work plan will be outlined in the deliverable 4.2.

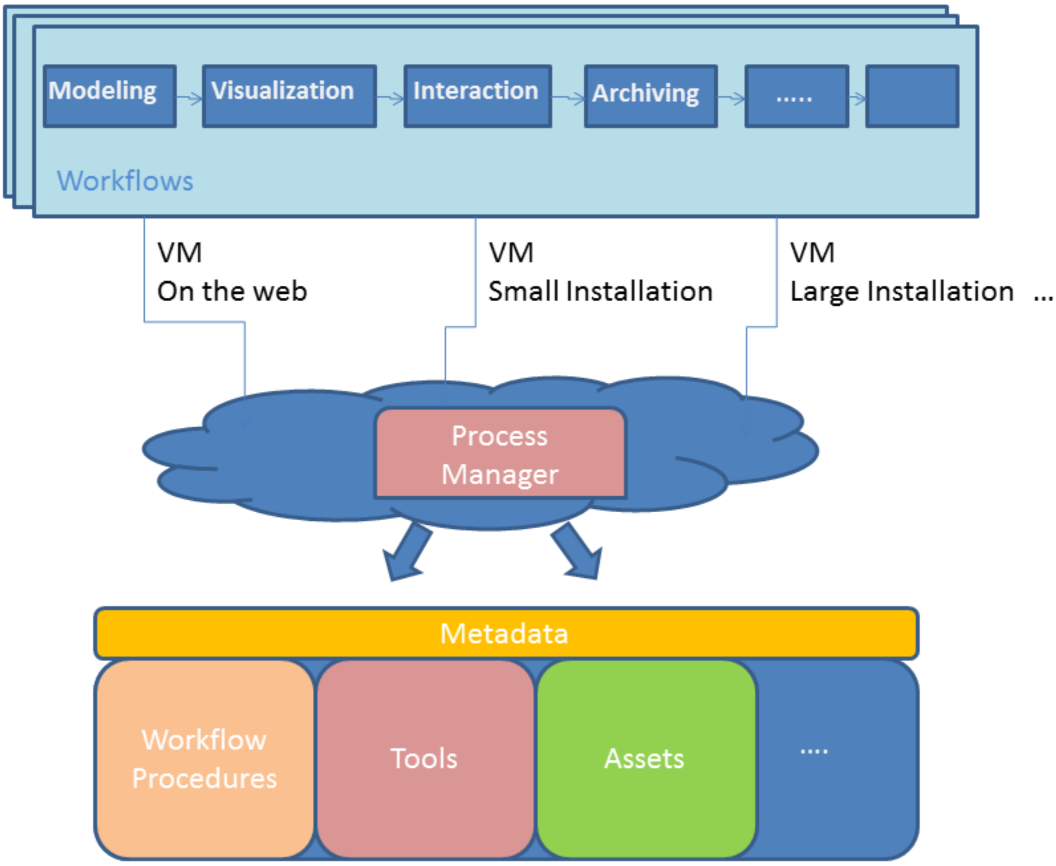

Figure 1. The V-MUST Platform

In order to better assess tools/technologies involved in the development of VM, some information have been collected through a technical questionnaire that was developed by the V-MUST partners. A selected and representative group of people involved in the development of Virtual Museums have been invited to fill it in. The results of this questionnaire are the basis to identify/define some of the needs and the current status of current VM development respectively deployment. This is helping us in the specification of the platform components. The questionnaire and the information collected are described in the next section (Section 3). We underline that some of the results coming from of this questionnaire will be used also in WP5, which concerns visualization/presentation tools; by the way, the questionnaire has been designed to cover the needs of both WP4 and WP5 in order to reduce and optimise information gathering overhead in separated timelines.

According to the preliminary analysis of needs with respect to user requirements during the house of questions, it turned out that aside 3D assets and tools also workflows and best practices to establish a VM in its different peculiarities (e.g. VM on the web, VM within a real museum, resp. fixed installations, etc.) have to be made available to the community. Those “workflows” describe issues related to the establishment of VM, its set-up, installation, archiving and re-use. Thus, Figure 1 describes a high level view on the services and layers required by the V-Must repository. It contains,the digital assets, tools as well as the adequate metadata and workflows, that will be organized within the repository. Among the different components that the platform should made available to the platform’s users, the repository plays a very critical role. In the next, after a detailed description of the requirements the repository must fulfill according to the specific V-MUST needs, we present and discuss some of the solutions which are available (tools from previous EC projects, open source solutions, commercial-off-the-shelve (COTS) systems) with a particular attention dedicated to the repository technologies developed by the EC IP “3D-COFORM” project.

At the end, we present some conclusions and an overview of the resulting work plan we intend to follow for the development of the V-MUST platform.

3. The design of the V-Must Technical Questionnaire

This section describes the structure of the questionnaire that we have designed to gather information on: the needs of practitioners involved in the design and implementation of virtual museums; the available technologies adopted so far; the perceived shortcomings of available technologies; their wish-list for the future. The questionnaire has been designed thanks to the involvements of many of V-MUST partners, in order to guarantee a good cover of the many topics discussed in previous House of Questions and Deliverables (in particular related to the WP2); according to this purpose, after a first preliminary design by CNR, the questionnaire structure and content has been extensively discussed by partners (at the project meeting in Seville on last June 2011 and by email communications).

After this collective design and refinement phase, CNR has implemented the survey using an open, web based survey tool: the LimeSurvey (http://www.limesurvey.org/) open source system, a flexible and powerful system to manage online questionnaire. The LimeSurvey system is also capable to store many information, like the time required by the users to fill the answers, and process it in several ways to do statistics and/or summarize the received answers.

The following section shown the questionnaire as presented to the stakeholders. The questionnaire has to be filled directly on the Web.

In order to ensure high quality in the answers received, we preferred not to open the survey to everybody, but to select a set of informed and high-experience users. Our community is pressed nowadays by too many requests to fill up surveys, and most of our colleagues are used to immediately trash those types of requests. Moreover, opening the survey to an undifferentiated user population has the inherent risk that many of the people filling it could be not expert or not motivated, bringing some noise in the final results of the survey.

Therefore, our policy was to ask to all the V-MUST partners to select a set of proper users/institutions to whom the survey should be directed; the selection criteria was strong commitment and experience in the survey subject, that should be assessed by partners on the basis of their experience in the field and knowledge of the different national domains.

Therefore, this selection process allowed us to select a pool of representative experts in Virtual Museum, coming from different experiences and differente EU countries, that have been invited to fill the questionnaire. Before to receive the invitation almost all the invited people have been asked for their availability in providing feedback about their experiences with Virtual Museums projects. This process, that required some time and coordination, allowed us to get a high percentage of responses from the selected users (much more than for survey sent in a blind way to a very large emailing list).

The following subsection presents the questionnaire.

3.1 The Questionnaire

Welcome! This questionnaire will take approximately 30 minutes to be completed. Thank you for the time dedicated to it.

There are 33 questions in this survey

Basic information

[Q1] Name *

Please write your answer here:

[Q2] Your Role *

Please write your answer here:

[Q3] Your Institution/Company (name, city, country) *

Please write your answer here:

[Q4] Type of Institution you work for *

Please choose **all** that apply:

- ▢ Hosting one or more Virtual Museums
- ▢ Developed internally one or more Virtual Museums
- ▢ Commissioned one or more Virtual Museums to be developed
- ▢ Has been involved in projects related to Virtual Museums
- ▢ No previous experience with Virtual Museums or similar
- ▢ Other: ____

[Q6] Your email *

Please write your answer here:

[Q7] In case you implemented a Virtual Museum / installation for a museum or a CH institution, please, provide the name of the application, its location and a reference name of a people involved

Please write your answer here:

[Q8] What is the content of the Virtual Museums / installations developed/commissioned?

Please write your answer here:

Previous experience

[Q9] Have you designed and/or implemented a Virtual Museum, a multimedia installation, an interactive kiosk, or similar applications for your institution or for a museum/institution you are collaborating with?

Please choose **only one** of the following:

- ▢ Yes
- ▢ No

[Q10] Why?

Only answer this question if the following conditions are met:
Answer was 'No' at question [Q9]
Please choose **all** that apply:

- ▢ no interest in adding interactive multimedia stuff in the current exposition
- ▢ lack of space to effectively displace the interactive presentation in the current exposition
- ▢ lack of money to cover implementation and maintenance costs
- ▢ lack of technical skills for the design and implementation
- ▢ Other:

[Q11] Which type of installation, from the following ones, have you implemented ?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question [Q9]
Please choose **all** that apply:

- ▢ user-passive (non-interactive multimedia presentation, video or computer animation)
- ▢ user-active (multimedia or interactive systems where the user can drive the presentation)
- ▢ both

[Q12] Which one of the following multimedia data were used in your installation/Virtual Museum?

Please choose **all** that apply:

- ▢ text
- ▢ 2D images
- ▢ panoramic images
- ▢ video
- ▢ computer animation

- ▢ 3D models
- ▢ sound/music
- ▢ voice reading a text
- ▢ Other: ____

[Q13] How much does your hosting/commissioning Institution invest, in this type of activities, per year?

Please write your answer here:

[Q14] Have you designed / implemented a software tool for Cultural Heritage applications (e.g. a particular service, a proprietary tool for content creation, a visualization tool, a measurement tool, etc.) ?

Please choose **only one** of the following:

- ▢ Yes
- ▢ No

[Q15] Please, describe in few words the tool developed

Only answer this question if the following conditions are met:

Answer was 'Yes' at question [Q14] (Have you designed / implemented a software tool for Cultural Heritage applications (e.g. a particular service, a proprietary tool for content creation, a visualization tool, a measurement tool, etc.) ?)

Please write your answer here: ____

____

Evaluation of user satisfaction

[Q16] Have you conducted an evaluation of the usability of the installation/Virtual Museum you commissioned / implemented?

Please choose **only one** of the following:

- ▢ Yes

- ▢ No

[Q17] Which type of methodology have you used?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question [Q16] (Have you conducted an evaluation of the usability of the installation/Virtual Museum you commissioned / implemented?)
Please choose **all** that apply:

- ▢ questionnaire filled in by the users
- ▢ interviews with the users
- ▢ observation of users' behaviour
- ▢ Other:

[Q18] Global user appreciation was ?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question [Q16] (Have you conducted an evaluation of the usability of the installation/Virtual Museum you commissioned / implemented?)
Please choose **all** that apply:

- ▢ very positive
- ▢ good
- ▢ neutral
- ▢ negative

Enabling technologies used (digital workflow)

[Q19] If you created panoramic images, which system have you used to build them ?

Please choose **all** that apply:

- ▢ Panotools

▢ Hugin

▢ Microsoft ICE

▢ PTGui

▢ KolorAutopano

▢ Other: ____________________

[Q20] If you used 3D models, which modalities you have used to create them ?

Please choose **all** that apply:

▢ manual modeling (e.g. 3DSMax, Maya, Blender)

▢ 3D from stream of images, multi stereo-matching (e.g. Arc3D, PMVS, Adamtech)

▢ user-driven photogrammetry (e.g. ImageModeler)

▢ stereo-based acquisition with calibrated camera rigs (e.g. ZScan)

▢ short-range 3D scanning (laser scanning or structured light)

▢ long-range 3D scanning (time-of-flight)

▢ proprietary system (please, describe it in the 'Other' field)

▢ Other: ____________________

[Q21] If you have produced 3D models through acquisition (e.g. 3D scanning) which post-processing tools have you used ?

Please choose **all** that apply:

▢ RapidForm

▢ MeshLab

▢ GeoMagic

▢ Cyclone

▢ NeXT Engine Scan Studio

▢ Optocad (by Breuckmann)

▢ Other: ____________________

[Q22] If you have produced computer animations, which software tools have you used ?

Please choose **all** that apply:

- ▢ 3DStudio Max
- ▢ Blender
- ▢ Cinema 4D
- ▢ Maya
- ▢ Other: ____

[Q23] Which systems have you used to support the implementation of your passive or interactive system ?

Please choose all that apply and provide a comment:

- ▢ Macromedia Director / Flash
- ▢ Standard web authoring system
- ▢ Proprietary system

[Q24] In case your system supports the interactive manipulation / navigation with 3D models, which technologies have been used ?

Please choose **all** that apply:

- ▢ X3D / VRML
- ▢ Acrobat3D
- ▢ Low-level graphics API (e.g. OpenGL, DirectX)
- ▢ Games development platforms/engines or scene graphs (e.g. Torque, XNA, OpenSG, Unreal)
- ▢ Other: ____

[Q25] How do you store/archive your digital assets?

Please choose **all** that apply:

- ▢ standard backup with no further information
- ▢ repository with additional information regarding the assets stored
- ▢ repository with metadata associated to each digital asset
- ▢ repository with semantic capabilities for further handling of the stored assets
- ▢ Other: ____

[Q26] If your application / installation supports the interactive manipulation / navigation with a 3D model, which interaction devices have been used ?

Please choose **all** that apply:

- ▢ standard mouse
- ▢ multi-touch surfaces (e.g. Apple IPad or Microsoft Surface)
- ▢ 3D location system (e.g. magnetic or optical tracking)
- ▢ gesture detection system (e.g. infra-red detectors, camera-based tracking)
- ▢ Other: ____

[Q27] Which type of output devices have been used in your system ?

Please choose **all** that apply:

- ▢ standard display (e.g. lcd/led monitor)
- ▢ multi-display (e.g. several screens aligned)
- ▢ stereoscopic display
- ▢ video projection on large screen
- ▢ immersive systems / cave-like devices
- ▢ table or workbench (e.g. Microsoft Surface)
- ▢ mobile devices (e.g. IPhone, Android-based devices)
- ▢ guest devices (e.g. standard/custom mobile device used inside a museum)
- ▢ Other: ____

Future plans

[Q28] Is your Institution planning to design and/or implement any type of Virtual Museum / installation ?

Please choose **only one** of the following:

- ▢ Yes
- ▢ No

[Q29] When ?

Only answer this question if the following conditions are met:

Answer was 'Yes' at question [Q28] (Is your Institution planning to design and/or implement any type of Virtual Museum / installation ?)

Please write your answer here: ______________________________

____

[Q30] Please, describe briefly what you plan to develop / commission ?

Only answer this question if the following conditions are met:

Answer was 'Yes' at question [Q28] (Is your Institution planning to design and/or implement any type of Virtual Museum / installation ?)

Please write your answer here: ______________________________

____

[Q31] Would you establish an online Virtual Museum presenting 3D assets on the Web ?

Please choose **only one** of the following:

- ▢ Yes
- ▢ No

[Q32] What kind of information would you like to present ?

Only answer this question if the following conditions are met:

° Answer was Y'Yes' at question '30 [Q31]' (Would you establish an online Virtual Museum presenting 3D assets on the Web ?)

Please choose **all** that apply:

- ▢ 3D assets representing physical heritage objects
- ▢ 3D virtual reconstruction hypothesis
- ▢ virtual tours through the real museum
- ▢ narrations related to the 3D heritage
- ▢ Other: ____

[Q33] What type of services would you use if a platform for heritage driven media exists ?

Please choose **all** that apply:

- ▢ authoring services
- ▢ asset services providing access to a digital repository
- ▢ document repositories
- ▢ information broker services (job services, exhibition planning services, etc.)
- ▢ Other: ____

Perceived technological issues and requirements

[Q34] How do you rate the availability of the following support/systems, possibly either Open Source or available at extremely low cost (0: not necessary / not interesting , 5 : really important)

Please choose the appropriate response for each item:

	1	2	3	4	5
Tools for building 3D models	○	○	○	○	○
Tools for the creation of computer animations	○	○	○	○	○
Tools for producing panoramic images	○	○	○	○	○
Tools for the design and implementation of an interactive installation	○	○	○	○	○
Tools to support the design and the implementation of storytelling	○	○	○	○	○
Tools to support the creation of content for stereoscopic display	○	○	○	○	○
Tools for the management of innovative interaction devices and modalities (e.g.	○	○	○	○	○

gesture-based interfaces)					
Tools for the presentation and communication of 3D assets on the Web	○	○	○	○	○
A Web repository to search for available basic digital assets (elements to be used in the design of an installation/VM, such as images, video or 3D models)	○	○	○	○	○
The availability of a common platform for the commercialization of digital assets produced in previous project (e.g. allowing revenue generation from the digital production process)	○	○	○	○	○
In case a repository for the secure storing, retrieval and commercialization of digital assets will be developed by V-MUST network, do you think that you will use it ?	○	○	○	○	○
In case a repository for the secure storing, retrieval and commercialization of digital assets will be developed by V-MUST network, do you think that you will contribute by providing content to it ?	○	○	○	○	○

Thank you for completing this survey.

3.2 Results coming from the collected information

Since the analysis of the collected information is quite complex (see Annex 2 of this document for a summary of only the multiple or single-choice answers of the questionnaire) we opt to report here just a synthetic bullet list with some considerations produced after the study and analysis of the questionnaire results, drafted according to the aims of the V-MUST.Net in general, and our focus on the V-MUST Platform in particular. We underline that what write in the following taking into account both the information collected with the technical questionnaire and the experiences in the field of the V-MUST partners. Many of the considerations and conclusions drawn are not limited to the questionnaire information, and many of them are supported and confirmed by the questionnaire data.

- **Number of filled questionnaires:** As a result of the first phase, a list of 50 stakeholders have been invited to fill the questionnaire. From this, the 70% (i.e. 35 people) have filled the questionnaire (in most cases in a complete manner; in a few ones, users have left some questions un-replied because they felt to be not sufficiently competent/expert to give an informed opinion). Two of them have declined to answer, after accessing the questionnaire, because they found the questionnaire too much technical for their know-ledge. Please note that many questions in the questionnaire were rather technical; the goal of running a selection of potential experts was exactly aimed at reducing the number of people without sufficient experience, and thus having only 2 out of 50 in this condition is a verification of the good work done at the polled experts selection stage.

- **Backgrounds polled:** About half of the people that filled the questionnaire are curators/manager of museums or CH institutions, the rest are people coming from the ICT domain (with specific expertise in the design of VM, developed for third parties, mostly CH institutions).
- **Which basic raw data:** Advanced multimedia digital assets, such as panoramic images, computer animation and 3D models, are widely used in Virtual Museums. This gives the impression that the domain is actively willing to endorse the new media emerging from research and development in ICT, and less conservative than usually though to be.
- **Tools specific for raw data:** For many advanced multimedia assets, some tools (discussed later) emerged as commonly perceived as the generic processing resources. Concerning panoramic images, there are no common tools due to the availability of many different tools to create panoramic images, none of which is still perceived as the prominent tool.
- **Passive vs. Interactive:** Interactive systems are the majority of the systems developed so far for museums installations. This underline the importance of producing agreed guidelines to design and support interactive system.
- **Usability evaluation:** Not so many stakeholders did evaluate the usability of their installations/VMs. It is not completely clear if this is a matter of lack of interest or lack of expertise or simply, the information collected are not completely reliable from this point of view and institutions do not want to dedicate resources to this type of studies.
- **Managing geo-referenced location (GPS):** Some stakeholder are interested in GPS in VM. This is not properly address by the V-MUST technical questionnaire, but, according also to previous discussion with the V-MUST partners this interest should be taken into account during the V-MUST platform development.
- **3D modelling:** 3D Studio Max is still the most used tool for the manual 3D modeling of artifacts or scenes. Open Source solutions, such as Blender, are also employed and are gaining momentum.
- **Output systems:** Video projection on large screen and multi-display devices are often used for museums installation.
- **Willingness to produce digital assets on the web platform:** More than 60% of the people who filled the questionnaire consider as a must the development of VM on the Web. Many V-MUST partners also find this as a common need and a good practice, especially in the context of developing stuffs that could be easily re-usable and portable.
- **SW tools for 3D:**
    - X3D is often used in the development 3D interactive systems.

- ○ Low-level API and game engine for custom are often employed in the development of interactive systems.
- ○ MeshLab and RapidForm are the more frequently used tools for the post-processing of 3D models acquired through laser scanning.

- **Open source tools:** In the last part of the questionnaire the people are asked to assess the importance of the availability of open source tools (or alternatively low-cost tools) to do several activities often related to the development of VM. The following rate summarizes, in a scale that range from 1 to 5, which tools are considered important and which are considered less important:

TOOLS (in order of importance) FOR:

BUILDING 3D MODELS	3,64
THE CREATION OF COMPUTER ANIMATIONS	3,25
DESIGN/IMPLEMENT INTERACTIVE INSTALLATION	3,20
MANAGEMENT OF ADVANCED INTERACTIVE DEVICES	3,14
FOR THE PRESENTATION/COMMUNICATION OF 3D THROUGH THE WEB	2,86
PRODUCING PANORAMIC IMAGES	2,82
FOR DESIGN/IMPLEMENT STORYTELLING	2,57
SUPPORT THE CONTENT CREATION OF STEREOSCOPIC DISPLAY	2,39

REPOSITORIES OF DIGITAL MULTIMEDIA ASSETS - MOST USEFUL USES

SEARCH FOR AVAILABLE BASIC DIGITAL ASSETS TO BE USED IN DESIGN OR DEVELOPEMENT OF VIRTUAL MUSEUMS	3,03
YOU WILL USE A (V-MUST) REPOSITORY FOR STORING, SHARING, RETRIVAL, COMMERCIALIZATION OF DIGITAL ASSETS	2,89
YOU WILL STORE CONTENT IN A (V-MUST) REPOSITORY FOR STORING	

SHARING, RETRIVAL, COMMERCIALIZATION OF DIGITAL ASSETS	2,82
PLATFORM FOR THE COMMERCIALIZATION OF DIGITAL ASSETS PRODUCED IN VIRTUAL MUSEUMS PROJECTS	2,78

In the next sections we use the considerations point out here to: first, present and discuss what software resources are available in public domain or on the marked fulfilling the needs of our users; second, to finalize a preliminary list of technological tools which are needed as components of the V-MUST platform.

4. Use of Technological Tools

This section describes the tools used in the context of Virtual Museums, both to produce the basic digital assets (i.e. the different types of basic digital multimedia assets, such as panoramic images, 3D models, computer animations) and to develop the virtual museums where such assets are used/exhibited. The tools are basically subdivided into two categories: tools for *basic content creation* and tools for the *development of the VM itself*.

4.1 Tools for Basic Content Creation

4.1.1 Panoramic Images

A panoramic image is an image created starting from pictures of a certain scene, e.g. a landscape or a site of interest, taken from the same point in different directions, which condensate all the visual information of these views. The panoramic image can be easily navigated, changing freely the viewpoint, with suitable tools (also through the Web). The information collected through the questionnaire demonstrated that many many tools are available for the creation of panoramic images; and that no one emerge as the most used. This is not a problem since almost all of these tools produce a spherical or a cylindrical image that can be used by different viewing tools for the navigation/visualization task. A brief description of some of these existing tools follows.

PTGui (http://www.ptgui.com)

PTGui is a cheap solution for the creation of gigapixels panoramic images available for Windows and Mac platform. HDR imaging is also supported. The online viewer provided is written in Flash, so it is supported by almost all the main Web browsers.

PanoTools (http://panotools.sourceforge.net)
PanoTools is a set of Open Source software tools originally developed by Professor Helmut Dersch of the University of Applied Sciences of Furtwangen. Behind it there is a wide community of developers, Its development has been supported also by the Google Summer of Code. The main limitation is the complexity of use but the availability of source code make this tools suite available for all the platform.

HUGIN (http://hugin.sourceforge.net/)
HUGIN is a graphical user interface which attempt to simplify the use of PanoTools. Anyway, the complete power and functionalities of the PanoTools suite can be expressed only by using the command-line version.

Kolor AutoPano Pro (http://www.kolor.com)
It is a professional commercial software for the generation of panoramic images. It includes many advanced features for color adjustment and moving objects removal in order to minimize ghosting effects. HDR imagining is also supported. The AutoPano Giga is the version of the same software to handle hundreds of images in the panorama generation. The price of both version is very low (around two hundreds of euros).

IPIX (http:/www.ipix.com)
IPIX is an integrated hardware/software solution to create 360º panorama. The system is delivered ready-to-go, and allows the generation of panoramic images in just two or three shots thanks to the fish eye lens provided. The price are around 2,500 dollars but we have to consider that all the necessary photographic hardware (e.g lens,.support device, digital camera) is included.

RealVIZ Stitcher (http://stitcher.realviz.com)
RealViz Stitcher is now be acquired by the Autodesk changing its name in Autodesk Stitcher Unlimited. It includes many features such as the generation of spherical images starting from both a set of images or two shots with fish eye lens. Different exposures, color adjustment and other ghosting artifacts are minimized in the generated images. The price is reasonable low, around 300-350 canadian dollars.

4.1.2 3D Models Acquisition and Processing
3D models are widely used in Virtual Museums, to show a collections of objects, to build a virtual reconstruction, to plan a virtual restoration, for documentation purposes, and so on. 3D models can be build from scratch manually with a geometric modeling software by an

artist/designer or acquired automatically through laser scanning techniques or image-based modeling. Computer Vision techniques can also be employed to generate the model automatically starting from a set of images. Here, we concentrate on the software tools usually employed for the generation and the post-processing of the acquired models. According to the feedback received *Meshlab* and *Rapidform* are the most used software tools for the creation and post-processing of scanned 3D models.

Meshlab (http://meshlab.sourgeforce.net)

MeshLab [meshlab2007, ARCH3D2011] is an Open Source multi-platform mesh processing tools mainly developed by the Visual Computing Laboratory of the CNR-ISTI to manipulate, clean, filter, and visualize 3D objects. Meshlab is renewed for being able to read and write a wide number of 3D file formats, but, beside this point, the real strength of MeshLab relies on the wide variety of mesh processing functionalities that it offers. The vast majority of these functionalities is exposed as a large set of filters that take in input one or more meshes, some user specified parameters, and then output one or more new mesh or other generic computed information. MeshLab offers around two hundred different filtering operations, categorized into menus according to a few keywords (remeshing, cleaning, sampling, texture, color processing, quad mesh processing, point clouds, etc). The simple functional structure of filters is implemented through a plugin framework that hides all the GUI coding allowing for a very simple development of additional plugins by new developers. Beside those filters there is also a small set of interactive tools that allows to perform more editing-like actions over the mesh like selection, painting, picking of points, taking linear measures, etc. The majority of the functionalities just mentioned are related to the 3D scanning pipeline, from the alignment to color mapping passing from the surface generation. These features, with the capability to handle also data coming from image-based reconstruction tool such as Arc3D [ARC3D] or PhotoSynth (based on the technology developed in [SNAVELY2006]) have make it one of the most used tools for 3D objects production and management in the Cultural Heritage field.

MeshLab is also able to visualize the models in very different ways. The rendering functionalities have be designed with two main objectives in mind: to provide rendering modes that make easier to inspect a mesh; so we included a number of shaders to allow for example a see-through view of the object or visualization of reflection lines to evaluate the fairness of the surface normals. For example, X-ray rendering mode allows to see through the models and get an intuitive idea of the interior of an object. MeshLab can be used also to make easy the creation of appealing snapshots for reports, papers or presentation. To do this it offers, for example, shadow mapping, screen-space ambient occlusion, configurable backgrounds, tiled renderings for very high resolution snapshot and the possibility of copy/pasting the camera parameters from text files.

RapidForm (http://www.rapidform.com)

Rapidform XOS (the RapidForm software tool for 3D scanning processing) is a reverse engineering software tool, available for the Windows operating system,. which offers a set of automatic features to handle the whole scanning pipeline (e.g. mesh alignment, surface creation, color mapping). One of the most important features is a wizard that assist the user in the creation of the 3D model starting from the acquired range maps. The native data format of most of the commercial 3D scanners can be imported in RapidForm. The range maps so imported can be cleaned with, for example, hole removals operation, or smoothed in order to avoid noise. Cloud point can also be aligned. One of the main interesting features is the export of the 3D model generated into a set of NURBS that can be used in many other geometric modeling. The 3D model can be also exported for 3D printing in STL format.

As previously stated, with Meshlab, this is one of the most used tools for the generation and post-processing of scanning data.

GeoMagic (http://www.geomagic.com)

According to the company which develop this 3D reverse engineering and inspection tool it is used by several industrial customers worldwide to turn 3D scan data into usable 3D data. Fields of applications are automotive, aerospace, turbine machinery, medical devices, dental CAD/CAM, consumer products, entertainment, art and archaeology. Even if one of the main field of application of this software is the creation of personalized devices and treatment procedures to improve patient care, it is also used to reconstruct, national treasures, archaeological finds and works of art.

Cyclone (http://www.leica-geosystems.it/it/Leica-Cyclone_6515.htm)

This is the proprietary software of the Leica Geosystem for the processing of point clouds, in particular for their alignment. It is very powerful in the handling of huge amount of acquired data. It is also capable to import data coming from non-Leica scanners such as Riegl and Faro. Models creation functionalities can be added through several modules such as the AutoCAD CloudWorkx which allows the users to efficiently generate AutoCAD models directly from the point cloud data. It is mainly employed by Leica scanners users for architectural/building reconstruction.

Optocad

This software is the scanning software system provided by the Breuckmann structure-light scanner. It handles all the stages of the standard scanning pipeline. One of its main characteristics is that the alignment phase should be perform during the acquisition campaign. Even if this could be a limitation in some cases it is very fast due to the zippering algorithm employed and it allows the user to inspect quickly the status of the acquisition of the object of interest during the acquisition campaign. Functionalities to handle color information are not currently available.

4.1.3 Computer Animation

Concerning the generation of computer animation the main tools used for the creation of this type of digital assets are 3D Studio Max, Cinema 4D, Blender and Maya. Among those, Maya and Cinema4D are more focused on the entire pipeline, providing an incredibly reach set of features. Maya is one of the most powerful tool from a technical point of view but it is require a lot of effort in terms of money and time to learn to use it in a professional way. According to this, in the context of V-MUST platform, we opt for Blender, since it is the only open source solution of this type, but the complete support for 3DS Studio Max is mandatory due to its wide use demonstrated by the feedback received.

3D Studio Max (http://usa.autodesk.com/3ds-max)

Autodesk® 3ds Max® software provides powerful, integrated 3D modeling, animation, rendering, and compositing tools that enable artists and designers to more quickly ramp up for production. It is available in two versions that share core technology and features, but offer differentiated experiences and specialized toolset for game developers, visual effects artists, and graphic designers on the one side, and architects, designers, engineers, and visualization specialists on the other.

According to the data collected and the opinions of the V-MUST partners 3D Studio Max is one of the most used tools for the modelling of virtual objects to use in VM projects. One of the main motivation of this could be its smooth learning curve to produce even quite complex 3D objects/scene.

Maya (http://usa.autodesk.com/maya)

Autodesk® Maya® is one of the most modern and professional solution for modeling, animation, creation of visual effects, rendering and compositing. Many people working in film, games, television, advertising, publishing, and graphic design production, use this toolset in their production. It is very expensive and require a lot of expertise to exploit its maximum potential.

The main difference between Maya and 3D Studio Max is that 3D Studio Max is an all-in-one solution (even if many plug-ins and tools are available to expand functionalities) that are good for many users while Maya is design with the goal to provide the maximum flexibility, modularity and customization in order assist the artist/technicians to obtain any type of production of any complexity (e.g. a high-budget Hollywood movie). Mainly for this reason we think that, except particular cases where an high-budget production of a computer animation is necessary for the needs of a certain VM project, many of the functionalities/tools available are not necessary in the general case. In fact, the feedback received underline that Maya is rarely used in the context of Virtual Museums production.

Cinema 4D (http://www.maxon.com)

Cinema 4D Studio is a suite of tools that can be used in every stage of the production of a computer animation. The suite includes advanced character tools, to make easy the creation of characters rigs; hair/fur tool, a physics engine to perform complex collisions and interaction between objects and an unlimited clients network for rendering. It may be seen similar to the 3D Studio Max in its philosophy, and in fact it has also very similar functionalities and learning curves. A in-deep comparison is difficult also for an expert users/designer.

Blender (http://www.blender.org)

Blender is the only Open Source solution for the development of all the stages to create a computer animation, from the modeling of the 3D objects involved in the animation, to the definition of camera paths and object dynamics, to the post-production effects.

Starting in 1988, Ton Roosendaal co-founded the Dutch animation studio NeoGeo which became the largest 3D animation studio in the Netherlands. At a certain point of the growing of the NeoGeo company, Ton, both artist and software developer, decided that in-house 3D tool set of the NeoGeo was too old and cumbersome to maintain and upgrade, and needed to be rewritten from scratch. In 1995 this rewrite began and was destined to become the 3D software creation suite we all now know as *Blender*. Nowadays, Blender is supported by the *Blender Foundation* which primary goal is to continue developing and promoting Blender as a community-based open source software.

One of the main limitation of Blender is its complexity from the user point of view; this motivates perhaps the fact that many people involved in Virtual Museum design and development do not use it to create computer animation but prefer more commercial solutions. Despite this problem, according to the V-MUST aims, we have to consider that thanks to the fact that Blender is an Open Source solution and that it is also highly and easily customizable through Python scripts, many advanced services can be implemented upon it, for example a remote rendering solution to preview a complex computer animation.

4.2 Tools for the development of VM

The development of Virtual Museums involves several technologies and tools in order to realize the final aim of a specific project. Taking into account that many Virtual Museums type are possible, as described in Deliverable 2.1, and even VM of the same type can have very different needs and use very different technologies we focus here mainly on the technologies for which we have been some feedback from the stakeholders and V-MUST partners. In the following we describe many technologies available for the development of the VM applications starting from the low-level technologies and go to the high-level ones. A particular emphasis is put on the technlogies that allow the deployment of the VM through the Web, finding them particularly interesting to guarantee both wide diffusion and long life to the VM. We do not discuss here tools specifically design to assist *storytelling* since the complexity of the workflow prevents at the moment to find technologies that can be considered a reference even if some attempts to develop integrate tools to facilitate storytelling development exists [Balet2007].

DirectX

Microsoft DirectX is a collection of application programming interfaces (APIs) for the development of multimedia applications, games in particulars. The name DirectX was coined as shorthand term for all of these APIs (the X standing in for the particular API names) and soon became the name of the collection. When Microsoft later set out to develop a gaming console, the X was used as the basis for the XBOX name to indicate that the console was based on DirectX technology.

Direct3D (the 3D graphics API within DirectX) is widely used in the development of video games for Windows, Xbox 360. Direct3D is also used by other software applications for visualization and graphics tasks such as CAD/CAM engineering. As Direct3D is the most widely publicized component of DirectX, it is common to see the names "DirectX" and "Direct3D" used interchangeably even if this is not correct.

Other APIs part of DirectX are, DirectInput, to control devices such as keyboards, joysticks and so on (nowdays replaced by XInput for XBox360) and DIrectMedia for multimedia playback and streaming media through the WWW.

We underline that this is a low-level APIs, only experts developer can use it to develop interactive applications in the context of Virtual Museums. The same consideration is valid from the API described below, i.e. the OpenGL.

OpenGL

OpenGL stands for Open Graphics Library and it is a multi-platform API, i.e. available on almost all the operating systems, to develop graphics application of any kind. More precisely, OpenGL is a specification written by the Khronos Group (which nowadays replace an international committee called ARB that written here in the last years) and it is the aim of each graphics hardware vendor to implement in the graphics driver its functionalities according to the hardware capabilities. Also this set of API is low-level and can be handled only by experts developers. The main feature is that guarantee portability of the developed application and long life since it is a technology widely used. *OpenGL ES* is the corresponding API for mobile devices like tablet and smartphone.

Flash

Flash is a technology developed by Adobe that allow the web programmers to develop "rich internet applications", i.e. web applications that include audio, video, graphics and so on. This is a valid alternative to other technology to deploy multimedia content on the Web and enrich web navigation even if it requires the installation of the Flash Player in your browser. Since few years ago 3D content cannot be handled natively in Flash, nowadays, Flash Player 11 has new functionalities to support 3D content, i.e. the *Stage3D* module. Stage3D, previously codenamed "Molehill," is a new set of of low-level GPU-accelerated APIs enabling advanced 2D and 3D capabilities across multiple screens and devices (desktop, mobile, and TV). The Flash technology is widely supported by all the major browser, even if it is not fully supported sometimes on certain platform, for example Apple iPhone does not support some Flash functionalities at the moment of writing.

WebGL

The delivery of 3D content via the web platform started to be a topic of interest since the graphics hardware of commodity personal computers became powerful enough to handle non-trivial 3D scenes in real-time. Many attempts have been made to allow the user of standard web documents to directly access and interact with three-dimensional objects or, more generally, complex environments from within the web browser. Historically, these solutions were based on software components in the form of proprietary and often non-portable browser plugins. The lack of a standardized API did not allowed web and computer graphics (CG) developers to rely on a solid and widespread platform, thus losing the actual benefits that these technologies could provide. In the same period of time in which GPUs showed a tremendous increase in performances and capabilities, the evolution of the technology behind web browsers allowed interpreted languages such as JavaScript to perform quite efficiently in general purpose computations, thanks to novel just-in-time (JIT) compilers such as TraceMonkey, V8 and SquirrelFish.

Thus, on one side, the hardware and software components have reached a level of efficiency and performances which could fit the requirements for high-quality and interactive rendering of 3D content to be visualized, on the other hand the increase of bandwidth for accessing the Internet allowed large volumes of data to be transferred worldwide in a relatively short amount of time. In this scenario, the need for a standardized computer graphics API became a high priority problem to be solved. In fact, in late 2009, the Khronos Group finalized a new standard, WebGL (see [Khronos2011] for the current specification) which aims at harnessing the power of graphics hardware directly within web pages through a JavaScript interface. WebGL is designed to closely match the OpenGL ES 2.0 specifications, with some modifications which make the API more close in look-and-feel to a JavaScript developer. On the other side, as web pages which use WebGL are freely accessible from every potential web client, the new specfiication impose a series of restrictions to comply with a more strict security policy.

Although this scripting language can not be considered as performant as a compiled one like C++, the tendency of delegating the most time consuming parts of a CG algorithm to the graphics hardware helps mitigating the performance gap.

X3D and X3DOM (http://www.x3dom.org)

Only few years ago to provide to the web browser 3D capabilities, the only solution was the installation of some additional plugins/components to the browser itself. The Flash technology just describe is an example of this approach. Besides the browser plugins approach, another recent more promising approach is to include 3D capabilities directly into the Web browser itself, by exploiting the WebGL specifications just mentioned. X3DOM and SpiderGL (described in the next) are both WebGL-based, allowing their direct use in the Web browser that supports the WebGL specification.

X3D is an open ISO standard that provides a portable format and runtime for developing interactive 3D applications. X3D evolved from the old VRML standard, describes an abstract functional behavior of time-based, interactive 3D multimedia information, and provides lightweight components for storage, retrieval and playback of real-time 3D graphics content that can be embedded into any application [Web3D2008]. The geometric and graphical properties of a scene as well as its behavior are described by a *scene-graph* [Akenine-Möller2008]. Since X3D is based on a declarative document-based design, it allows defining scene description and runtime behavior by simply editing XML without the need for dealing with low-level C/C++ graphics APIs, which not only is of great importance for efficient application development but also directly allows its integration into a standard web page. Further, using X3D means that all data are easily distributable and sharable to others. Despite proprietary rendering systems that all implement their own runtime behavior, X3D allows developing portable 3D applications.

The X3D specification includes various internal and external APIs and has a web-browser integration model, which allows running plugins inside a browser. Hence, there exist several X3D players available as standalone software or as browser plugin. The web browser holds the X3D scene internally and the application developer can update and control the content using the Scene Access Interface (SAI), which is part of the standard and already defines an integration model for DOM nodes as part of SAI [Web3D2009], though there is currently no update or synchronization mechanism.

To alleviate these issues, the *X3DOM* framework [Behr2009], a DOM-based integration model for X3D and HTML5, was presented to allow for a seamless integration of interactive 3D content into HTML pages. The current implementation is mainly based on WebGL [Khronos2011]. This allows X3DOM to run natively in the Web browser, taking the advantages to be available for every platform. Additionally, the X3DOM architecture also proposes a fallback model to allow for more powerful rendering backends, e.g. by exploiting flash 11 plug-in technology.

SpiderGL (http://spidergl.org)

SpiderGL is a javascript-based library that facilitate the development of graphics applications based on WebGL [Di Benedetto2010]. It is mainly developed by ISTI-CNR and it is very recent technology. Most of the current JavaScript graphics libraries implement the scene graph paradigm. Although scene graphs can naturally represent the idea of a scene, they also force the user to resort to complex schemes whenever more control over the execution is needed. There are several situations in which functionalities implemented by scene graph nodes cannot be easily combined to accomplish the desired output, thus requiring the developer to alter the standard behavior, typically by deriving native classes and overriding their methods or, in some cases, by implementing new node types. In these cases, a procedural paradigm, like the one of SpiderGL, often represents a more practical choice. Also, scene graphs contain a large codebase to overcome the limitations of strongly typed imperative programming languages, which is no more required in dynamic languages such as JavaScript.

SpiderGL is composed of several modules that provide the developers to many useful functionalities:

MATH: Math and Geometry utilities. Linear algebra objects and functions, as well as geometric entities represents the base tools for a CG programmer.

GL: Access to WebGL functionalities. The GL module contains a low-level layer, managing low-level data structures with no associated logic, and a highlevel layer, composed of wrapper objects, plus a series of orthogonal facilities.

MESH: 3D 3D object definition and rendering. This module provides the implementation of a polygonal mesh in order to allow the user to build and edit 3D models, and its corresponding version on the GPU side.

ASYNC : Asynchronous Content Loading. Request objects, priority queues and transfer notiers help the programmer to implement the asynchronous loading of data.

UI : User Interface. Similar to the GLUT framework; it includes a series of typical 3D manipulators allow a quick and easy setup of the web page with 3D viewports and provide an effective management of user input.

Concluding, we can state that SpiderGL is particularly suitable for the development of web graphics applications where advanced non-standard or complex CG algorithms have to be implemented. Complex 3D scenes that require scene-graph cannot be handled naturally.

OpenSceneGraph (http://www.openscenegraph.org)

A scene graph is a description of a virtual 3D scene through a set of interconnected nodes, each node could represents a 3D object or a part of it or to be related to events or containing other information. The interconnections help to define a logical structure and/or spatial relationship between the nodes. OpenSceneGraph (OSG) is a scene-graph based high performance 3D graphics toolkit for visual simulation, games, virtual reality, scientific visualization, and modeling. It provides high-level rendering features not found in the OpenGL API. OpenSceneGraph is very active and effective, several companies provide consulting, training, and support services based on OSG.

Since OpenSceneGraph is based on OpenGL and entirely written in C++ it is available for many platforms, including Microsoft Windows, Apple Mac OS X, GNU/Linux, IRIX, Solaris, HP-UX, AIX, and FreeBSD operating systems.

The source code of OSG is distributed under a specific license called OpenSceneGraph Public License (OSGPL). The OSGPL is based on the Lesser GNU Public License (LGPL) and includes the WxWidgets additions to LGPL, which clearly allows distribution with proprietary application.

The main features of OSG, except the obvious OpenGL rendering functionality are the following:

- Large, paged database support, including tools for creating geospatial terrain databases
- Multi-pipe and multi-display scalability
- Spatial organization
- Texture map font rendering
- Particle effects
- Shadows
- Bulk culling on the host CPU
- Level of detail control to optimize distant feature rendering
- Automatic sorting for correct rendering of partially transparent geometry
- State change minimization
- File I/O, including support for many popular 2D image and 3D model file formats
- Cross-platform access to input devices and rendering surfaces
- Multiple language support including Java, Python, and Lua
- Reflection interface for runtime binding

In the context of Virtual Museums scene-graph based technologies are quite used for handling complex reconstruction that allow also interaction with the user.

OpenSG (http://www.openSG.org)

OpenSG is a portable scenegraph system to create realtime graphics programs, e.g. for virtual reality applications. It is developed following Open Source principles (LGPL) and can be used freely. It runs on Windows, Linux, Solaris and MacOS X and is based on OpenGL. It is an Open Source scenegraph system for interactive 3D graphics application and was designed to be easy to use and extend, and to support all modern graphics features that the current generation of graphics cards provide. OpenSG in its version 2.0 has a slightly more specific vision in addition to its predecessor generic one. It is in line with OpenSceneGraph where both of them represent modern scenegraphs that grew out of the mess that happened in the second half of the 90-ies and ended in the demise of SGI and Microsoft's Fahrenheit project. They both learned a lot from older systems, and while OpenScenegraph leaned heavily on the Performer side of things in the beginning (the initial force behind it was the desire to have a certain Performer application running on Windows), OpenSG leaned more on the Fahrenheit side of taking scenegraphs to the next level and making them more general and flexible. Both of them have developed from there in the last few years.

InstantReality (http://www.instantreality.org)

The instantreality (IR)-framework is a high-performance Mixed-Reality (MR) system, which combines various components to provide a single and consistent interface for AR/VR developers. Those components have been developed at the Fraunhofer IGD and ZGDV in close cooperation with industrial partners. In its core building blocks IR consists of OpenSG as core rendering backend, HID, a network transparent device and data-stream management system, VisionLib, a flexible Vision/Image-pipeline processor and Avalon that enables dynamic scene management and system manipulation. The framework offers a comprehensive set of features to support classic Virtual Reality (VR) and advanced Augmented Reality (AR) equally well. The goal was to provide a very simple application interface while still including the latest research results in the fields of high-realistic rendering, 3D user interaction and total-immersive display technology. The framework provides a data-flow graph which is an extension to the X3D scene and related execution model. Those graphs allow the developer to create applications by modelling and not just programming. Any application consists of a number of graphs, which are defined by components and relations between those components. Each component includes state-parameters and a processing unit, which controls the behaviour of the component. The component complexity can scale from single boolean operation to complete application including geometry and simulation subparts. The processing unit of each component can be declared by a hidden subgraph, a script or a set of native compiled class. The resulting architecture is extremely flexible and allows the developer to create complex applications by a simple drag and drop interface. The final application-graph can be deployed in any supported runtime environment from a single smart-phone to a multi-screen/multi-node cluster unit.

Additionally, the framework includes various optimisation methods to exploit all available hardware resources to reach global application specific runtime goals:

- *Auto-Parallel/Multithread*: The system analyses the structure of the application graph in real-time and uses a patented method to detect independent sub-graphs and to execute them in parallel.
- *Cluster*: Different sort-first/sort-last algorithms balance the rendering load for every cluster-node in real-time. The method scales almost linear and is not fixed to the number

of CPUs. The algorithm allows increasing the overall cluster performance by increasing the number of render-nodes.

- *Multi-Resolution Datasets*: The framework can create and manage multi-resolution datasets for points, meshes and volume datasets. This allows the system to control the overall render performance to reach global application goals like a minimal frame rate.

IR is platform independent and complies to several standards currently required to set up virtual installations such as OpenGL 2.0 (Khronos Group), GLSL (Khronos Group), CG (NVIDIA corporation), X3D (ISO/IEC 19775:2004), JAVA (Sun corporation) SOAP (W3D SOAP V1.2), ZEROCONF (IETF Zeroconf WG).

OSG4Web

OSG4web is an joint initiative (CINECA and ITABC-CNR) to provide a framework for in-browser OpenSceneGraph (OSG) application wrapping. Dating back to 2004, the plugin-based has been used in different projects like VirtualRome [Calori2009] and, more recently, Aquae Patavinae project (http://www.vhlab.itabc.cnr.it/archeovirtual/acquaepatavinae.htm).

The OpenSceneGraph based application currently supports large terrain rendering, real time shadows, vegetation and particle effects. It can be easily configured. Constrained navigation is also supported. Being previously a Firefox-only plug-in, the code is going to support a much broader range of Web browser due to the usage of Firebreath (www.firebreath.org) framework. It could support Javascript bi-directional interaction with surrounding HTML page elements. allowing JavaScript access to exposed OSG applications API. This technology is particularly interesting for web browser-based visualization of large paged complex scenes (like large landscapes with geospecific terrains) that is one of the missing feature (or non trivial to implement) of many high-level engines of this type.

Torque (http://www.garagegames.com/products/torque-3d)

Sometime serious games found interesting applications also in the context of Virtual Museums, in particular for edutainment (education + entertainment) or communication purposes. In this ambit the game engine Torque is a technology that can be used. Torque is a game engine with many many features that allow the user to develop complex games with no so huge effort. Obviously, this is not limited to the development of serious game but also interactive applications such as an interactive virtual reconstruction can be developed. The costs of the Torque Game Engine is very low, and many tools for the different needs are available at very low price.

XNA Framework

The XNA Framework is another SDK for the development of videogames for both XBOX and mobile platform. According to the Microsoft documentation, the current version of this SDK is the *XNA Game Studio 4.0*. XNA Game Studio is a programming environment that allows the developer to use Visual Studio to create games for Windows Phone, Xbox 360, and Windows. It includes the XNA Framework, a set of managed libraries designed for game development based on the Microsoft .NET Framework. From our knowledge this technology is rarely used in Virtual Museums even if, generally speaking, game platform development for console like this one can gain diffusion due to innovative interaction capabilities of certain videogame controllers (i.e. Wii remote).

5. Repositories for Virtual Heritage. What they offer to users? What are the foreseen requirements?

An important component of the V-MUST platform is a repository for storing, sharing, searching, and, hopefully, commercialization, of digital assets related to Virtual Museums such as 3D models output of past 3D scanning projects, basic assets to speed up virtual reconstruction, historic images for documentation purposes, and so on. In this Section we attempt to answer to some questions about repositories and we outline the most important existing repository-related technologies in order to assess and support the development of the V-MUST repository.

What is a repository?

The term *repository* is used for many different technological topics, and is often misused in our domain. A commonly perceived need is to have some software system able to store the digital assets produced and to give easy access to those data. Providing access can be interpreted as providing local access (often restricted and protected) or opening access to the external world (with or without stringent control on the access rights and views). Providing access nowadays is no more perceived as we did in the past (accessing a database via SQL queries), but requires new and more sophisticated search and retrieval functionalities. Moreover, we need efficient tools for presenting the results of the queries (since most of the data we want to store are multimedia data, that require specific visual browsers to be communicated/presented to the users).

What do we store in repositories?

Let we focus on CH-related applications, for the sake of simplicity and to define better our specific needs. Our users might be interested to store in a repository *many different (but related) sources of information*:

- The **digital models** that have been built to represent a specific CH asset (an artwork, such as a statue, a vase, a painting; or a single building, up to an entire archaeological site or the urban centre of an historical city). Those digital assets are characterized by a very different scope (e.g. size of the artefact and density/resolution of the digital representation) and many different types (2D, panoramic 2D, 3D, terrains/geographical models, video/animation, 3D+time, …)

- The **raw data** produced by the sampling instruments used to produce the digital models above. In some cases we might be interested in storing both the raw data (e.g. for preservation purposes, and to be able to process again the data in the future, e.g. when better processing software will be available or different reconstruction needs might be defined by the final user). Connected with the raw data, we could be also be interested in storing the **provenance data** (which specify the sampling instrument used, how the final digital model has been derived from the raw data, the processing tools used and the specific parameters values set).
- Some **metadata** on the **effective artwork** that is represented by the digital model (I have a digital 3D model of the David. But which David? Sculptured by whom? When? In exposition where? etc.)
- Basic digital models are not all we have, since we are designing **composed digital assets** produced from those basic data. These entails passive computer animations (produced using some 3D models and some digital scenes) or entire interactive installations. In this case, several options can be adopted, like storing just the final product (easy for an animation, difficult for a complex interactive installation) or storing also the abstract content, by using some support for the specification of the story-telling/installation structure. This last solution has several difficulties but would guarantee high portability and re-use of developed VM projects.

Finally, we should consider also the technologies used to design and implement those repositories. There are many different solutions for the design of a repository, that range from the design of a basic archive (using consolidated technology based on relational databases) up to very sophisticated solutions that allow to encode knowledge networks (based on the CIDOC-CRM metadata system and recent derivations). The latter, for example, is the design strategy endorse by the EC 3DCOFORM project, where the focus is to grant to the CH expert (e.g. an art historian) maximal flexibility and power in both structuring the information encoded on the repository and composing semantic queries to the repository.

5.1 Initial hypothesis

According to the polling results, consolidated experience of the partners and the many discussions occurred in project meetings, we are convinced that designers of VM are focusing mostly on the management of the workflow of the *basic data components / digital assets* (the raw building blocks in the design of a virtual museum). Those include different data types: text, images, videos, computer animations, 3D models, audio files, etc.

In this phase we do not focus on the technology needed to store and manage the creation process of complex derived assets such as *virtual storytelling*. we adopt this decision since, even if of interest for part of the community, the current understanding and analysis of the workflow is insufficient to assess well what can be done in this direction. We might consider these and other advanced features later on, when the workflow analysis will be more clear and consolidated.

From the *authoring* side, some idea will be presented in the conclusions.

5.2 Ideal functionalities of a repository for supporting implementation of VM

We present in the following some characterizing aspects to be taken into account while presenting the features of a repository system and while assessing them in a comparative manner. These aspects will help us in the outline of the V-MUST platform development (deliverable 4.2).

1) Storing & preserving basic digital assets

Storing in a safe manner the assets, moving data from my PC/CD/DVD to a repository.

Advantages are:

- storing data somewhere else (storage as an infrastructure offered by a third party, relieving the user to buy and maintain large HDs/storage units, providing replication of storage)
- do not bother about backups - automatic backup service should be provided by the repository

Sub-specifications could be:

1.1) remote or local? (i.e. someone could prefer a local repository to have full control over the access of critical data)

1.2) do we have to deal with already established museums repositories? In this case we have to consider interoperability / federation

2) Granting feature for a controlled access of third parties to my data.

User registration service, controlled access rules, etc.

Sub-specifications could be:

2.1) basic access rules (any registered user sees everything)

2.2) metadata visible to all, access to digital assets restricted

2.3) flexible access rights management (each contributor could define different views over his data to different classes of users)

2.4) User identification and authorization: different schema exist that balance ease of implementation, security, scalability to high user number

2.5) Advanced DRM / commercial features such as image watermarking, encryption, E-commerce: has to be supported or just Support passive copy prevention DRM schema like image watermarking?

3) Storing metadata

The repository should not be limited to the storage of the digital assets, but should pair and interlinking those assets with the metadata that describe them.

Metadata should include:

- the data that characterize the object represented by the digital asset (historical data, usually well formalized in the several standards proposed in the CH community); this can be considered a rather consolidated topic;
- *provenance data*, i.e. the data that characterize the digital model creation pipeline/process (given a digital model, I am interested to know how that digital model has been produced: which reconstruction process, which acquisition system, which software, ...)

Sub-specifications could be:

3.1) capabilities for *metadata* encoding & ingestion

3.2) capabilities for *provenance data* encoding & ingestion

3.3) to distinguish between *basic* (mandatory) and *optional* metadata could help a lot a subsequent design of metadata input

3.4) automation of basic metadata extraction from real data, to allow "lazy" approach to ingestion (minimizing initial ingestion effort, allowing to subsequent metadata insertion)

3.5) Tools that produce and consume data from the repository should interoperate with metadata reducing at minimum the perceived overhead

4) Structure of the database

Database structure is implemented by means of a classical relational database structure (i.e. using standard technology)?

Does it adopts a more sophisticated and flexible approach (such as the semantic network proposed for the 3D-COFORM repository)?

We need to evaluate the gain in increased flexibility and semantic inference granted by semantic network versus the increased complexity of implementation and use (please note that the current mental model of CH operators is the one of standard relational databases; imposing a more sophisticated approach can lead to miss-use of the technology).

Moreover, while evaluating the level of flexibility and power of the different solutions, we should also consider the complexity of the *data ingestion process*. Users usually are very reluctant to spend time in entering the data in a repository system. Easy of use of the data ingestion interface is therefore a major evaluation factor, as well it is the amount of data that has to be provided by the users (since often asking a huge mass of data is the key for having the user deciding to either abandon a repository or entering highly incomplete data, that might nullify the effort in designing a very rich data infrastructure and result in a poor system due to lack of data).

Sub-specifications could be:

4.1) underlying model: relational vs. semantic network

4.2) Decoupling of data and metadata: the 3DCoform idea of having two distinct and separate component dealing with data (Object Repository) and metadata (Metadata Repository)

4.3) Policy regarding updates: should the data be immutable? (just creation and deletion, no update)

4.4) Distributed data over infrastructure, Centralization of access rights or federation of repositories?

4.5) Client API for tools integration: how handle proprietary tools that can not be modified? need for a file level API like Dropbox or WebDav mount

5) Query model

Which types of queries are supported (this is strictly related to the “Structure of the database”)

Sub-specifications could be:

5.1) free text queries

5.2) SQL-style queries

5.3) semantic reasoning

5.4) visual query?

5.5) do the query involve just meta-data and not data?

6) Visualization front end

Since we are focusing mostly on visual / multimedia assets, it is important to evaluate which functionalities does the repository / the query interface offers to visualize the results of the searches. Those will be presented with textual data (for synthetic presentation of results) but also will need to show in detail each single asset.

Sub-specifications could focus on the specific media supported:

6.1) still image

6.2) panoramic image

6.3) video (grabbed or synthetic like computer animation)
6.4) 3D model
6.5) audio file
6.6) Are the previous implemented in a web context or require specific plugins?
6.7) Automatic processing / filtering of data (format change, index feature extraction, format conversion,rendering)

7) Licensing, maintenance, funding

Since the repository organize, store, deliver, transform and preserve data, that are the most valuable good of VM stakeholders, it is important that the base technology offer long lasting support. Business model for data and metadata preservation and service support should be specified:

7.1) The repository is provided as a **service**. In this case it is necessary the definition of Service Level Agreements and with fees.
7.2) The repository technology is provided as a **proprietary licensed product**, hosted by independent cloud provider. In this case we have to define hardware resource impact and license fees.
7.3) The repository is provided as **Open Source.** In this case we need to define just hardware resource impact.

The first two cases requires thorough evaluation of the commercial bodies providing service / support. In the latter, if not willing to take the risk of complete in-house support, is the quality and soundness of the Open Source ecosystem (user community, supporting organization, developer activity) to be evaluated.

5.3 Previous Experiences on Repository Systems

This Section contains the description of several repository systems developed in past european projects in the ambit of Cultural Heritage.

5.3.1 ArcheoGrid

ArchéoGrid (http://archeogrid.in2p3.fr) is both a conservatory of CH projects related to the 3D reconstruction of ancient site or artefacts, and a set of tools and processes to assist the different steps of a scientifically validated reconstruction.

For this purpose, the main unit of the repository is the project itself. For each project, the following data associated with metadata are attached: in-site captures, out-site captures, iconography, texts, measure reports, images for previous possible 3D reconstructions, slides (this images are public), and finally, 3D data. Excepted the 3D data, each of these data may be visualized on-line.

The storage reflects this organization: each project is stored as a tree of directory, each sub-directory representing one kind of data. A database is associated in order to store the corresponding metadata. This allows an easy control access based on traditional file control access. To add a project in the repository, a request has to be done to the person in charge.

The associated metadata (information and comments added by every researchers to each data, if they want) mostly reflect the nomenclature of the spatial organization of the reconstructed object (semantic and hierarchical nomenclature, like an architectural organization). A hierarchical query can thus be performed on such metadata.

A special structure of “unicos” and “unitext”, a unique feature of Archéogrid, allows to select part of an image (resp. text) to create a new reference image (resp text) with more precise and refined metadata. These fragments of image or text allows having a more pertinent query in the database and a semantic manipulation of the 3D contents.

Potential evolution in the context of the V-Must platform

Currently, ArchéoGrid is a now long-standing system and as been used in number of projects. Theoretically, it can be used by anyone who requests to add a new project. For this, an interesting and easy-to-introduce feature will be to allow that the 3D data or others may be stored remotely, using others data repository. This way, ArchéoGrid will be connected to other systems.

Note that ArchéoVision is in charge of the French Conservatory of 3D data for archaeology and CH. This conservatory is associated with large computational power and storage size (TGE Adonis: http://www.tge-adonis.fr/), a national-wide infrastructure for archiving digital data in the Humanities and Social Sciences. This means that AchéoGrid repository preserves not only their own models, but also those entrusted to them as voluntary deposits. Thus, it can be used by the member of the consortium, without any limit of storage.

The project-centered organization of ArchéoGrid makes it suitable for some form of story telling. Indeed, the joint storage of 3D reconstruction with historical and digital document may help in explaining the hypothesis and in telling the story of such a reconstruction, even if no paradata as such is actually included.

However, it lacks currently some 3D visualization tools that can improve the navigation through the database. On the early years of ArchéoGrid, it was possible to navigate on the reconstructed 3D environment and by selecting a component, to visualize the different document that leads to such a reconstruction, together with the metadata. Unfortunately, this was only possible using a dedicated and proprietary system and 3D format. This functionality may be re-introduced, developing it in a different way, during the V-Must project. Another possible extension is the generalization of Unico and Unitext to every kind of stored data.

5.3.2 AIM@SHAPE

AIM@SHAPE is a project developed in the ambit of the 5th FW EU and it is now concluded. Its acronym stands for Advanced and Innovative Models And Tools for the development of Semantic-based systems for Handling, Acquiring, and Processing knowledge Embedded in multidimensional digital objects The Shape Repository developed in the AIM@SHAPE project has several aims. The primary goal is to provide a shared collection of standard test cases and benchmarks in order to enable efficient prototyping as well as practical evaluation on real-world and large-scale shape models. Its distinctive feature is a full documentation of the most interesting geometric properties provided by metadata and common shape onthology.

The AIM@SHAPE provides also a Tool Repository, i.e. an inventory of shared software that collects and documents a large number of state-of-the-art tools that can be used at different stages of the digital shape lifecycle. The aim of this repository is to avoid overlapping and reduce development efforts and speed up research by sharing established knowledge.

The search framework developed on the shape repository allow both semantic and geometric search. The Semantic Search Engine exploits the metadata provided and/or collected through automatic tools [Borgo2005]. Such metadata are arranged according to a proper shape onthology defined in the ambit of the project itself. The Geometric Search Engine provides content-based 3D shape retrieval mechanisms according to different similarity criteria and matching methods. This project is connected with the **FOCUSK3D** EU project, which main aim is to promote the adoption of best practices for the use of semantics in 3D content modelling and processing.

The repository technology proposed in AIM@SHAPE is advanced and provide also semantic search capabilities. The main focus of it is on shapes and theirs geometric properties and, mainly for this reason, not easily adaptable to the needs of the VM context.

5.3.3 3DCOFORM

The 3D-COFORM is an ongoing EU 7th FW IP project that has one overriding aim: to establish 3D documentation as an affordable, practical and effective mechanism for long term documentation of tangible cultural heritage. In order to make this happen the consortium is highly conscious that both the state of the art in 3D digitisation and the practical aspects of deployment in the sector must be addressed. Hence 3D-COFORM proposes an ambitious program of technical research, coupled with practical exercises and research in the business of 3D to inform and accelerate the deployment of these technologies to good effect.

One of the advanced technology developed in the ambit of this project is a semantic multimedia repository with advance reasoning capabilities. This repository (described in two papers [3DC-Rep20], [3DC-ObjRep]) is tailored on specific CH requirements. It is composed of two distinct component: one centralized meta-data repository supporting CIDOC-CRM meta-data storage, able to perform sophisticated search through reasoning based on a semantic network. The centralized components is also keeping tracks of needed access authorization needed to reach object data. The other component is the object repository which store the data that are treated as binary chunks identified by an unique UUID and identified by a mime type that define the trans-coding and filtering operation.

The objects repository are distribute among the different organizations in a federated schema, this allow storage to (potentially large) collections of data objects (text, image, multimedia, 3D assets) to be kept within owner organization boundary, granting better access performances as well as stronger control on valuable assets access. Object repository handle replica request for preservation as well as data pre-caching for application speed up. It also allow running of automatic meta-data content extraction filters within local repository.

This system has been designed almost from scratch and at the moment of writing this document it is in the last phase of its development. This very advanced repository will be able also to inter-operate with other 3DCoForm tools such as Meshlab and CityEngine and with some web services such as Arc3D.

A general licensing model has not yet been officially defined but facility to test and evaluation should be made available shortly.

5.3.4 CARARE

CARARE is a Best Practice Network, funded under the European Commission's ICT Policy Support Programme, which started on 1 February 2010 and will run for three years.

One of the main goal of the CARARE project is to help further development of Europeana (http://www.europeana.eu/portal). Europeana is an internet portal launched in 2008, with the goal of making Europe's cultural and scientific heritage accessible to the public. This internet portal acts as an interface to millions of books, paintings, films, museum objects and archival records that have been digitised throughout Europe and provided to the portal by Europeana partners. Around 1500 institutions across Europe have contributed to Europeana.

The activities of the CARARE network are:

- **Preparing and enabling the network** for content harvesting and aggregation. This work package will establish the technical approach for the project including looking at the metadata, terminology resources and IPR for the content to be harvested; a programme of work on SKOS, controlled vocabularies and place name gazetteers; and completing mappings between Europeana's schemas and the CIDOC CRM. It will make recommendations on issues specific to CARARE's domain.
- **Testing and prototyping** tools and services in the Europeana development environment to enable the aggregation of digital content from the archaeology/architectural heritage domain to Europeana. This work package will test the harvesting of content from each provider and commence aggregation services and metadata mapping tools for content providers to use.

- **Harvesting and aggregating** will establish the live service for the CARARE network and start the process of harvesting content and making it available to Europeana. In this workpackage content providers will prepare their metadata and content ready for presentation in Europeana and implement harvesting systems supported by the CARARE community. Training and guidance will be available through the network
- **3D and virtual reality** will establish the methodology for Europeana to provide a point of access to 3D/VR and for 3D content. The workflow will be established and documented through case studies and training materials.
- **Dissemination** activities will be carried out throughout the project to present the work of the CARARE network and Europeana at conferences, workshops and other events.
- **Sustainability** - this workpackage will investigate sustainable business models for the continued provision of services and the framework for extension of the network to include new partners.

According to the last statistics provided in June 2011, the Europeana contains a total of 19,1 million of digital items, from which:

- 12,7 million images: photos, paintings, drawings, postcards, posters
- 6 million texts: books, newspaper articles, manuscripts, letters
- 145,000 videos: movies, documentaries, TV broadcasts, public information films
- 272,000 sounds: cylinders, 78rpm discs, radio, field recordings

The approach proposed in the CARARE project is to develop a set of mapping tools to transform the information to ingest in a pre-defined metadata scheme. The current idea to include 3D object directly in attached pdf documentation through the U3D format.

(link to a white paper on CARARE technical approach)

5.3.6 Discovery Project

Supported from 2006 to 2009 by the eContentplus programme, the European project Discovery oriented to provisioning a technological infrastrucure to get access to Philosophical Content has two main components.

- **Philosource**, a federation of semantic digital libraries in the field of philosophy based on **Talia**, an open-source, Semantic Web based, distributed digital library and publishing system, designed specifically for humanities research. developed with Ruby on Rails web framework.
- **Philospace**, a network of personal desktop applications based on Dbin, running on a local machines connected via a peer-to-peer network. Used as a personal workspace for academic research, will enrich the content of *Philosource* with semantic annotations.

5.3.7 SAVE Project

SAVE stands for «Serving and Archiving Virtual Environments» and is lead by Bernard Frischer and the Virtual World Heritage Laboratory (http://vwhl.clas.virginia.edu/save.html) at the University of Virginia, USA. It's a project funded several times by the *National Science Foundation* in the USA since 2005.

SAVE is still in development (their public website only present what SAVE will be and is not active yet) and will be designed to act as both an on-line peer-reviewed journal in which scholars can publish 3D digital models AND a central repository accessible to different users with various services. In the long term, they envision a peer-reviewed, searchable, interoperable repository of scientifically authenticated 3D model.

Its main goal is to offer scholars in the fields of virtual archaeology and architectural history the opportunity to publish on the Internet their 3D digital reconstructions as fully interactive models in accordance with the double-blind reviewing system. This is why one of the prerequisite is to present the underlying documentation giving transparency to the end-user about the hypothesis of reconstruction of the major elements of the model. Thus, all models will have to be accompanied by metadata, documentation, and a related article or monograph explaining the history of the monument and its state of preservation, as well as an account of the modelling project itself.

ACCESS AND INTERACTIVITY

The user interface intends to offer three modes of accessing a 3D model: *Global*, *High resolution* and *Collaborative*. The first mode, *Global*, makes a schematic version of the 3D model with simplified geometry and reduced texturing available in a KMZ layer in Google Earth. The *High resolution* makes the full model available with full interactivity, real-time lighting, and some simple tools while the *Collaborative* presents a somewhat simplified version of the model enhanced with social tools such as avatars, VOIP, and instant messaging to facilitate the use of the model in teaching and research. All the modes are mutually accessible to the subscribers.

Depending of the user accessing the 3D models, different options are also envisaged. For example, companies will be able to automatically download and license a model for commercial use in derivative products while schools and universities will have the possibility to obtain site licenses for the use of multiple copies of a model. Curators at virtual heritage centres can easily find just the models they need to create comparative or globalized exhibitions.

3D models will be seen in two views: authorial and editorial. In the authorial view, the user sees the model in its original form (i.e., how it was built by a specific creator). In the editorial view, the user sees how the editorial board of SAVE has remixed elements of different models of the same 3D monument made by two or more authors. The editorial view thus gives the end user the Editorial Board's judgement of the "best of the best" available in visualizing how a particular 3D site or monument should be reconstructed. Additionally, a blog will be associated with each publication in SAVE, so that SAVE subscribers can comment on the model. The editorial board will monitor the logs to see if any criticisms or suggestions have been posted that might warrant a response by the creator of the model. The creator and editorial board will have the opportunity to update or correct the model.

ISSUES ADDRESSED

Some of the issues actually addressed and studied by the SAVE development team is certainly of interest to the V-Must consortium (see Koller *et al.2009*):

- *DRM and Secure Transmission*. New research directions are suggested for protected dissemination of 3D models, both with a posteriori steganographic watermarking methods, and techniques for developing a trusted graphics pipeline to prevent piracy. Useful techniques envisaged include secured remote rendering, in which high-resolution versions of the 3D models are stored on remote servers and only rendered 2D images are transmitted to end users; the remote rendering approach endorsed by the SAVE project is the one proposed by Stanford and CNR in the Siggraph 2004 paper (see Koller *et al. 2004*).
- *Metadata*. Three types of metadata are envisaged for the sake of transparency of the model:
  - *Catalog Metadata*: in accordance with the Dublin Core schema, for indexing and searching*;*
  - C*ommentary Metadata:* paradata. Explanations about the choices made for the reconstruction (one of the main challenge addressed by the London Charter);
  - *Bibliographical Metadata:* sources used for the reconstruction.

They also strongly suggest an interactive exploration mode of these metadata (but no firm solution are envisaged at the moment).

- *Uncertainty.* Of course, it is of vital importance that a system for sharing scientifically authenticated 3D models directly facilitates accurate, conspicuous documentation of the uncertainties inherent in the models. Different ideas are studied, but again, no firm solutions are proposed yet:
  - *A new 3D Symbology;*
  - *Animation or Rendering Techniques;*
  - *Combining Textual Metadata with 3D Visualization.*
- *Version Control*. They anticipate developing solutions for a 3D model version control system with the following features:
  - *Tracking of Every Addition, Deletion, and Modification to 3D Models;*
  - *3D Difference Computation and Visualization*. This capability could use geometric analysis algorithms and information visualization techniques to automatically identify and then visually highlight the variations among 3D models;

- o *Delta Compression for 3D Models.*

ACTUAL STATE

In the last year (2010), Frischer's group has been working with the ENEA-GRID project, Italy, to experiment on the development of the cyber-infrastructure needed to support SAVE. This ENEA-GRID is another significant project of repository to have a look on (see Abate *et al.*) and concerns the implementation of a hardware and software architecture that allows remote access to a repository of three-dimensional models (high resolution, multi-disciplinary, available via the internet, and provided and uploaded by registered users).

A pilot version of the SAVE project is envisioned soon. This overview is based on the articles [Abate2011], [Koller2009] and [Frischer2006] and not on an experimentation of the system itself.

5.3.8 DARIAH

Digital Research Infrastructure for the Art and Humanities is a concluded project to support the digitisation of arts and humanities data across Europe.

DARIAH has now moved into the transition phase: in this phase, that should start next year, DARIAH will submit an application to the European Commission to establish a European Research Infrastructure Consortium (ERIC). This legal framework will facilitate the long-term sustainability of DARIAH.

In the previous phase, some demonstrator have been set up:

- UK ADS has been one of the most active promoter, supporting two demonstrator that use it' s service platform (that is likely to be proposed as foundation in the coming second phase) : ARENA and its successor ARENA2 that is web-service based
- The TEI (encoded text) demonstrator based on Max Plank eSciDoc

They seem to be providing recommendations and guidelines and possibly some practical result: a Technical reference architecture (WP7) as well as a Conceptual model (WP8)

According to the site, the project should "*provide a coordinated technical infrastructure for supporting the preservation of cultural heritage in Europe, and will enable dramatically improved access to research material for the humanities*": so could be useful to track it' s progress and establishing contacts, as some technology and best practice could be beneficial to V-Must infrastructure.

5.3.9 SHAMAN

Is a Large Integrated Project within the Seventh Framework Programme with many industrial partners with the mission:

"To establish an Open Distributed Resource Management Infrastructure Framework enabling Grid-Based Resource Integration, reflecting, refining and extending the OAIS model and taking advantage of the latest state of the art in virtualisation and distribution technologies from the fields of GRID computing, Federated Digital Libraries, and Persistent Archives;"

It has a web service architecture it seem to use a storage layer inter-operable with IRODS and to promote Xeproc an open source tool for helping ingestion by using template, according to its distributed ingestion demonstrator document

Links to search for EC projects which might have developed some repository-like technology:

- http://ec.europa.eu/information_society/activities/econtentplus/projects/funded_projects/index_en.htm
- http://cordis.europa.eu/fp7/ict/telearn-digicult/digicult-projects-fp7_en.html
- http://cordis.europa.eu/fp7/ict/telearn-digicult/digicult-projects

5.4 Available Open Source solutions / components

IRODS

The Integrated Rule-Oriented Data System, is an open source (BSD license) data and meta-data storage building block for data grids. It has proven scalable ranging from moderate collections from small communities to multi-server collections with hundred million files totalling petabytes of data.

It's has a good support by core development (the DICE Center at the University of North Carolina) and a wide and active community of thousands users from different community and institutions all over the world. it has several built-in features supported by the core development team as well as numerous extensions.

It stores and searches meta-data inside a relational database (PostgreSQL, MySQL, Oracle) while it provides different storage options for data.

It supports rule based system to implement data transformation work-flows based on a set of (extensible) micro-services: the micro-services can be extended at installation time and can wrap external web services. They could be used to support filters for file format transformation, data reduction, automatic meta-data extraction.

IRODS supports out of the box a replication system as well as features for organizing multiple instances into a federated data storage.

IRODS stores meta-data into a very simple key-value format within a relational database while it has a pluggable storage system, usually on file-system but supporting also other kind of storage (Amazon S3 cloud storage)

Presentations

Moore 2011

Documented evaluation and experience

LMLUISA Irods usage in Finland for image in microscope, integration with various tools through fuse / webdav access, reason to use

iREAD JiSC 2009 evaluation report

SHAMAN EU project demonstrator D11.2 deliverable

JISC evaluation of Shibboleth - iRODS integration

Integration

Integration with Fedora project some hints

Integration with Dspace

Kindura: early stage project for Irods Integration with DuraCloud (DuraSpace)

Access methods

iDrop : DropBox like client for ingestion

FUSE :

Performance testing of iRODS FUSE (unstable)

Evaluation of FUSE at NASA (satisfactory for read-only, problems for read -write)

Davis a WebDav Irods client

Client API in Java (jargon), PHP (Prods) and Python (Pyrods)

Fedora Commons

"Flexible Extensible Digital Object Repository Architecture" is a (complex) but feature rich framework for developing full fledged digital asset management, supported under DuraSpace umbrella. It requires Java-Tomcat technology as well as a relational DB. Fedora instances are diverse and their contents range from financial and scientific data to published works, records management, technical data, and other areas of digital asset management. It is used as component in several projects that could be explored as example of integration components:

eSciDoc, a Digital library platform supported by Max Plank that use Fedora (currently 3.4) as one of it' s key component.

Islandora, from University of Prince Edward Island: it combines Drupal and Fedora software

ADSplus : Fedora implementation project by UK Archeology Data Service

Fedora supports the Mulgara Semantic RDF-Triplestore and with Resource Index module provides the infrastructure for indexing relationships among objects and their components. The Resource Index module can be extended to include the storage of the metadata used in your system.

There is an effort from IRODS community to extend Fedora IRODS as data storage component, see this presentation (2009)

DSpace

Open source software originally developed by MIT Libraries and Hewlett-Packard (HP) is a turnkey institutional repository application, supported under DuraSpace umbrella. It requires Java-Tomcat technology as well as a relational DB.

It implements Dublin Core meta-data schema and can manage a wide spectrum of content types and has been used by many institutions (mainly academia).

A comparison between DSpace and Fedora is accessible here.

Related project to DSpace is SIMILE, that extend metadata schema support in DSpace through RDF/Semantic Web technologies.

Eprints

Open Source platform developed for supporting open access publication initiative by promoting authors self-archiving their publications.

As the first professional software platform for building high quality OAI -compliant repositories, EPrints is already established as the easiest and fastest way to set up repositories of open access research literature, scientific data, theses, reports and multimedia. According to its installation requirements it is structured as a perl based web application supported by RDBMS (Mysql-Oracle).

Merritt

Repository service from the University of California Curation Center (UC3) with an architecture based on micro-services : it seems a service provided to California University at reimbursement price, part of several services are based on open source components like BagIt or D-flat but id does not seem fully open the storage model seem file-system based while the ingestion service seem based on manifest (examples).

6. CONCLUSIONS AND FUTURE PLANS

According to what presented and discussed in this overview about the current available technologies for repository, content creation tools and development tools for Virtual Museums, a detailed work plan for the design and the implementation of the V-MUST platform should be developed in the next months (deliverable 4.2). Some initial ideas and discussion on our plan are presented as follows.

Concerning the *repository* issue, since basic functionalities such as storing/sharing/searching should be the main aim of the V-MUST platform, from our analysis of the state of the art it is possible to conclude that:

- the ArcheoGrid approach seems to be promising as a basic platform building block for providing a repository for V-MUST in view of long-term archiving;
- the final deployment of the 3DCOFORM repository technology should be follow with particular care in order to assess better which components of such repository can be employed in the future V-MUST platform. 3DCOFORM repository components guarantee that more advance features in terms of metadata handling and reasoning could be included in the V-MUST platform, an aspect that it is not possible to obtain relying on the ArcheoGrid or currently available solutions;
- we should also consider that the goals at the base of the design of the 3DCOFORM repository infrastructure are much wider than the basic needs of potential V-MUST users, as it comes from the results of the repository. Building up a very complex knowledge network as the one provided by 3DCOFORM seems a very powerful solution for providing reasoning features to the art historians willing to use the system for supporting research and sophisticated queries. Conversely, the functionalities needed for the design of virtual museums seems more basic and simple. According to this a more simple design, based on consolidated relational database technology, could be sufficient and more easy to populate/use for this specific community of users.

About the services/tools that should be provided by the V-MUST platform, the analysis confirms that the best approach to support the community involved in the development of Virtual Museums is to provide both a collection of tools and some basic/advanced Web-based services. For example, we will include *MeshLab* and with high probability a future version of the *Community Presenter* as representatives tools of interest. The Community Presenter, is a technology developed in the framework of the 3DCOFORM project; it is a declarative ambient which helps the developers in the implementation of interactive presentations of virtual collections for VMs/kiosks/installations with "standard" functionalities.

Concerning potential *web-based services,* one that will be surely included in the V-MUST platform is a set of conversion tools between multimedia data formats in order to create the "glue" for existing and future developed tools. In this context the X3D format (and most probably COLLADA) is the most suitable data format for exchanging 3D models between different tools. The conversion between 3D Studio Max and Blender data format emerges also as a need from the analysis, especially if some rendering services will be developed; a remote rendering should necessarily be Blender-based, for licensing and customization reasons, and therefore conversion from other formats to the Blender one will be necessary.

Another mandatory service that the V-MUST platform should provided is some support for web-based deployment of 3D content. Just to mention an obvious example, we will have to provide remote web-based visualization on the repository, to support the preview of the 3D assets stored in the repository. This and other 3D-based services related to the repository will be implemented through X3DOM with the help of SpiderGL for features that require a lower-level approach.

7. ANNEXES

7.1 Annex 1 - Bibliography

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7.2 Annex 2 - V-MUST Technical Questionnaire

In this section we summarize the feedback received by the V-MUST Technical Questionnaire. The detailed answers provided by the stakeholders are not reported here.

Q4 – Type of institution you work for	**No.**	**%**
Hosting one or more Virtual Museums	5	15.15%
Developed internally one or more Virtual Museums	13	39.39%
Commissioned one or more Virtual Museums to be developed	7	21.21%
Has been involved in projects related to Virtual Museums	**20**	**60.61%**
No previous experience with Virtual Museums or similar	4	12.12%
Other	2	6.06%

- developer of virtual museum software
- research in museums

Q9 - Have you designed and/or implemented a Virtual Museum, a multimedia installation, an interactive kiosk, or similar applications for your institution or for a museum/institution you are collaborating with?

Yes (Y)	**23**	**76.67%**
No (N)	6	20.00%
No answer	1	3.33%

Q10 – Why? (in case of negative answers to Q9)

no interest in adding interactive multimedia stuff in the current exposition	0	0.00%
lack of space to effectively displace the interactive presentation in the current exposition	1	16%
lack of money to cover implementation and maintenance costs	**3**	**50%**
lack of technical skills for the design and implementation	2	32%
Other	2	32%

- no particular reason
- Interested, but hasn’t started yet

Q11 – Which type of installation, from the following ones, have you implemented ?

user-passive (non-interactive multimedia presentation, video or computer animation)	1	3.03%
user-active (multimedia or interactive systems where the user can drive the presentation)	5	15.15%
both	**18**	**54.55%**

Q12 – Which one of the following multimedia data were used in your installation/Virtual Museum?

Text	18	54.55%
2D images	21	63.64%
panoramic images	9	27.27%
video	18	54.55%

computer animation	16	48.48%
3D models	**24**	**72.73%**
sound/music	19	57.58%
voice reading a text	12	36.36%
Other	6	18.18%

- augmented reality (id 9)
- AR overlays (id 16)
- GPS-missions in an open landscape
- Spazialized voices - Voci spazializzate
- don't know
- none yet

Q14 - Have you designed / implemented a software tool for Cultural Heritage applications (e.g. a particular service, a proprietary tool for content creation, a visualization tool, a measurement tool, etc.) ?

Yes (Y)	10	33.33%
No (N)	**16**	**53.33%**
No answer	4	13.33%

Q16 – Have you conducted an evaluation of the usability of the installation/Virtual Museum you commissioned / implemented?

Yes (Y)	10	33.33%
No (N)	**17**	**56.67%**
No answer	3	10.00%

Q17 - Which type of methodology have you used?

questionnaire filled in by the users	7	21.21%
interviews with the users	**8**	**24.24%**
observation of users' behaviour	6	18.18%
Other	1	3.03%

- videos

Q18 – Global user appreciation was?

very positive	**8**	**80.00%**
good	2	20.00%
neutral	0	0.00%
negative	0	0.00%

Q19 - If you created panoramic images, which system have you used to build them ?

Panotools	2	6.06%
Hugin	0	0.00%
Microsoft ICE	0	0.00%
PTGui	2	6.06%
KolorAutopano	0	0.00%
Other	**7**	**21.21%**

- VR worx, Adobe Photoshop
- IPIX
- Realviz tools

- Skyskan, Watchout
- Gigapano, KRPano
- Panorama factory
- Don't know specific details

Q20 - If you used 3D models, which modalities you have used to create them ?

manual modelling (e.g. 3DSMax, Maya, Blender)	**18**	**54.55%**
3D from stream of images, multi stereo-matching (e.g. Arc3D, PMVS, Adamtech)	5	15.15%
user-driven photogrammetry (e.g. ImageModeler)	3	9.09%
stereo-based acquisition with calibrated camera rigs (e.g. ZScan)	2	6.06%
short-range 3D scanning (laser scanning or structured light)	11	33.33%
long-range 3D scanning (time-of-flight)	7	21.21%
proprietary system (please, describe it in the 'Other' field)	1	3.03%
Other	2	6.06%

- 3D SOM
- Skyskan real time

Q21 - If you have produced 3D models through acquisition (e.g. 3D scanning) which post-processing tools have you used ?

RapidForm	5	15.15%
MeshLab	**10**	**30.30%**
GeoMagic	3	9.09%
Cyclone	2	6.06%
NeXT Engine Scan Studio	2	6.06%
Optocad (by Breuckmann)	2	6.06%
Other	5	15.15%

- PointStream
- Cloude Cube
- Riscan Pro, etc.
- Work done by ISTI-CNR
- Polyworks

Q22 - If you have produced computer animations, which software tools have you used ?

3DStudio Max	**12**	**36.36%**
Blender	6	18.18%
Cinema 4D	7	21.21%
Maya	6	18.18%
Other	0	0.00%

Q23 - Which systems have you used to support the implementation of your passive or interactive system ?

Macromedia Director / Flash **12** **36.36%**

- Plus VirTools 3D Via

Standard web authoring system	8	24.24%
Proprietary system	6	18.18%

- Silverlight and Quartz Composer
- Skyskan

- XVR

Q24 - In case your system supports the interactive manipulation / navigation with 3D models, which technologies have been used ?

X3D / VRML	**8**	**24.24%**
Acrobat3D	2	6.06%
Low-level graphics API (e.g. OpenGL, DirectX)	12	36.36%
Games development platforms/engines or scene graphs (e.g. Torque, XNA, OpenSG, OSG, Unreal)	**8**	**24.24%**
Other	3	9.09%

- Unity
- internal tool - VEX CMS
- XVR

Q25 - How do you store/archive your digital assets?

standard backup with no further information	**16**	**48.48%**
repository with additional information regarding the assets stored	5	15.15%
repository with metadata associated to each digital asset	4	12.12%
repository with semantic capabilities for further handling of the stored assets	3	9.09%
Other	0	0.00%

Q26 - If your application / installation supports the interactive manipulation / navigation with a 3D model, which interaction devices have been used ?

standard mouse	**16**	**48.48%**
multi-touch surfaces (e.g. Apple IPad or Microsoft Surface)	11	33.33%
3D location system (e.g. magnetic or optical tracking)	3	9.09%
gesture detection system (e.g. infra-red detectors, camera-based tracking)	7	21.21%
Other	3	9.09%

Q27 - Which type of output devices have been used in your system ?

standard display (e.g. lcd/led monitor)	**16**	**48.48%**
multi-display (e.g. several screens aligned)	9	27.27%
stereoscopic display	9	27.27%
video projection on large screen	**15**	**45.45%**
immersive systems / cave-like devices	9	27.27%
table or workbench (e.g. Microsoft Surface)	5	15.15%
mobile devices (e.g. IPhone, Android-based devices)	10	30.30%
guest devices (e.g. standard/custom mobile device used inside a museum)	2	6.06%
Other	1	3.03%

- Head mounted display

Q28 - Is your Institution planning to design and/or implement any type of Virtual Museum / installation ?

Yes (Y)	11	39.29%
No (N)	2	7.14%

No answer	**15**	**53.57%**

Note: See DETAILED ANSWERS (Q29) for the planning about design/implementation.

Q31 - Would you establish an online Virtual Museum presenting 3D assets on the Web ?

Yes (Y)	**16**	**57.14%**
No (N)	2	7.14%
No answer	10	35.71%

Q32 – What kind of information would you like to present ?

3D assets representing physical heritage objects	11	33.33%
3D virtual reconstruction hypothesis	**12**	**36.36%**
virtual tours through the real museum	11	33.33%
narrations related to the 3D heritage	10	30.30%
Other	0	0.00%

Q33 - What type of services would you use if a platform for heritage driven media exists?

authoring services	12	36.36%
asset services providing access to a digital repository	**17**	**51.52%**
document repositories	15	45.45%
information broker services (job services, exhibition planning services, etc.)	4	12.12%
Other	3	9.09%

- The V&A woudl always see these types of servcies as being built inhouse rather thasn hosted elsewhere.
- RM compliant 3D visualization (e.g. remote rendering engine)
- Don't know

Q34 - How do you rate the availability of the following support/systems, possibly either Open Source or available at extremely low cost (0: not necessary / not interesting , 5 : really important)

Q34-SQ001 Tools for building 3D models

1 (1)	0	0.00%
2 (2)	0	0.00%
3 (3)	2	7.14%
4 (4)	4	14.29%
5 (5)	**16**	**57.14%**
No answer	6	21.43%

Q34-SQ002 Tools for the creation of computer animations

1 (1)	0	0.00%
2 (2)	0	0.00%
3 (3)	1	3.57%
4 (4)	7	25.00%
5 (5)	**12**	**42.86%**
No answer	8	28.57%

Q34-SQ003 Tools for producing panoramic images

1 (1)	1	3.57%
2 (2)	1	3.57%
3 (3)	**7**	**25.00%**
4 (4)	5	17.86%
5 (5)	7	25.00%
No answer	7	25.00%

Q34-SQ004 Tools for the design and implementation of an interactive installation

1 (1)	1	3.57%
2 (2)	1	3.57%
3 (3)	7	25.00%
4 (4)	4	14.29%
5 (5)	**10**	**35.71%**
No answer	5	17.86%

Q34-SQ005 Tools to support the design and the implementation of storytelling

1 (1)	2	7.14%
2 (2)	2	7.14%
3 (3)	5	17.86%
4 (4)	4	14.29%
5 (5)	**7**	**25.00%**
No answer	8	28.57%

Q34-SQ006 Tools to support the creation of content for stereoscopic display

1 (1)	0	0.00%
2 (2)	**7**	**25.00%**
3 (3)	6	21.43%
4 (4)	5	17.86%
5 (5)	3	10.71%
No answer	7	25.00%

Q34-SQ007 Tools for the management of innovative interaction devices and modalities (e.g. gesture-based interfaces)

1 (1)	1	3.57%
2 (2)	3	10.71%
3 (3)	2	7.14%
4 (4)	5	17.86%
5 (5)	**11**	**39.29%**
No answer	6	21.43%

Q34-SQ008 Tools for the presentation and communication of 3D assets on the Web

1 (1)	0	0.00%
2 (2)	2	7.14%
3 (3)	4	14.29%
4 (4)	6	21.43%
5 (5)	**8**	**28.57%**
No answer	8	28.57%

Q34-SQ009 A Web repository to search for available basic digital assets (elements to be used in the design of an installation/VM, such as images, video or 3D models)

1 (1)	1	3.57%
2 (2)	2	7.14%
3 (3)	5	17.86%
4 (4)	5	17.86%
5 (5)	**9**	**32.14%**
No answer	6	21.43%

Q34-SQ010 The availability of a common platform for the commercialization of digital assets produced in previous project (e.g. allowing revenue generation from the digital production process)

1 (1)	2	7.14%
2 (2)	4	14.29%
3 (3)	3	10.71%
4 (4)	6	21.43%
5 (5)	**7**	**25.00%**
No answer	6	21.43%

Q34-SQ011 In case a repository for the secure storing, retrieval and commercialization of digital assets will be developed by V-MUST network, do you think that you will use it ?

1 (1)	1	3.57%
2 (2)	3	10.71%
3 (3)	**8**	**28.57%**
4 (4)	5	17.86%
5 (5)	6	21.43%
No answer	5	17.86%

Q34-SQ012 - In case a repository for the secure storing, retrieval and commercialization of digital assets will be developed by V-MUST network, do you think that you will contribute by providing content to it ?

1 (1)	1	3.57%
2 (2)	0	0.00%
3 (3)	**8**	**28.57%**
4 (4)	6	21.43%
5 (5)	6	21.43%
No answer	7	25.00%