Evaluating the Creation and Preservation Challenges of Photogrammetry-based 3D Models

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Abstract

Though the roots of photogrammetry can be traced back to photography's earliest days, only recent advances in both digital technology and software applications have put the possibilities of 3D modeling from 2D source images in the hands of the greater cultural heritage community. The possibilities of such 3D digital rendering are many. With these possibilities come unique digital preservation challenges. This study explores basic close-range photogrammetry as applied to sample archival objects. Additionally, the latest BagIt and ZIP-based bundling formats along with repository-based solutions are also surveyed as potential 3D data management and archiving aggregators for resulting 3D models.

Background

Photography's transition from traditional film to digital capture combined with parallel advances in digital post-processing have together broadened the possibilities of many computational imaging approaches. Photogrammetry [1][2], a technique born during photography's earliest days, is one such method that has enjoyed the fruits of these recent trends.

In turn, photogrammetry has become an intriguing alternative for the computational creation of 3D objects from 2D digital still images within cultural heritage institutions where it has many potential uses. Interactive 3D data models allow for the recording and analysis of surfaces and volume that intuitively mimic human stereo vision. Fragile and rare objects of high value can be manipulated non-destructively through virtual surrogates within software applications [3]. Conservationists can use such models over time to assist in condition assessments [4][5][6]. Finally, analog surrogates can also be reproduced through the 3D printing of an object's 3D dataset.

With these models come unique digital preservation challenges. This paper investigates the basics of close-range photogrammetry capture, post-processing, and potential strategies for the archiving of resulting 3D data models.

Basic 3D Model Reconstruction with Agisoft PhotoScan 1.1

Agisoft's PhotoScan [7] is a photogrammetric processing tool that has been leveraged by a growing number of cultural heritage 3D modeling projects [8][9][10][11]. One of the software's main virtues is that it allows for the processing of both metric and non-metric cameras. As a result, common DSLR cameras and standard lenses can be used in initial 2D still image data acquisition using conventional photography techniques. Such camera and standard lens combinations are calibrated automatically by PhotoScan which also adds to it ease of use.

For isolated objects, an assortment of best practices applies towards original image capture. For example, low distortion, flat field prime lenses are preferable. Images should overlap and cover all surfaces, as the software cannot re-construct full model geometry without complete source image coverage.
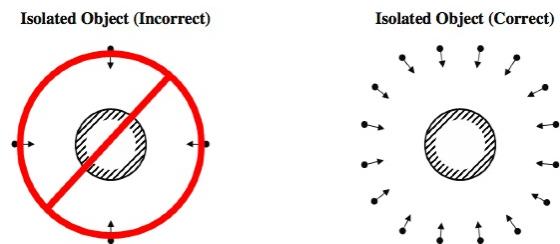

Figure 1. *Correct image capture, Agisoft PhotoScan User Manual - Standard Edition, Version 1.1.*

Focus and focal distance should also remain consistent from image to image. Unedited camera raw images are then normally rendered to TIF or JPEG. As PhotoScan relies partly on camera-written image file Exif data and standard lens profiles in its 3D re-constructions, it is important that source images are loaded into the program uncropped.

Once imported, source images are auto-aligned by the program based upon selected parameters. PhotoScan then builds an initial sparse point cloud, followed by a dense point cloud of the object. The dense point cloud is based upon the software's ability to estimate camera positions from the source images, which allows the program to calculate depth information for each camera to be combined.
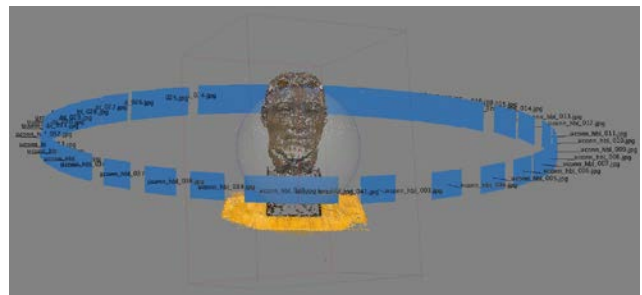

Figure 2. *Auto-aligned camera images and resulting dense point cloud, Agisoft PhotoScan v1.1, (virtual model by author).*

A geometrical mesh is then interpolated from point cloud data. Corrections, such as the removal of detached components and the closing of holes can be performed within the program. Excessive geometry resolution can also be removed through

subsequent mesh decimation. Finally, model texture can be built using a number of different user-chosen mapping modes [13].
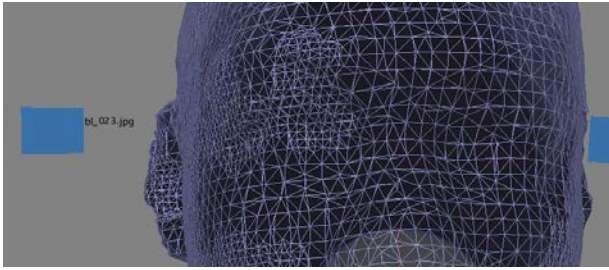

Figure 3. Close-up of 3D polygonal mesh, Agisoft PhotoScan v1.1 (virtual model by author).

Figure 4. Close-up of final 3D model texture, Agisoft PhotoScan v1.1 (virtual model by author).

3D Model Exports

PhotoScan allows for the saving and exporting of various stages of model reconstruction in a variety of formats. It can export point cloud data in OBJ, PLY, XYZ text file format, ASPRS LAS, ASTM E57, U3D, potree, PhotoScan OC3, and PDF. 3D models can be exported in OBJ, 3DS file format, VRML, COLLADA, PLY, STL, Autodesk FBX, Autodesk DXF, U3D, and PDF. PhotoScan "project files" which are wrapped and saved to the Postscript-based PSZ compressed format can also be archived. These project files can contain a list of loaded 2D source images, masks applied to the photos, depth maps for cameras, a dense point cloud model, a reconstructed 3D polygonal model with user edits, and mesh and texture reconstructions [14].

With this array of options naturally arrive questions on current best practice towards the archiving of such 3D model datasets.

3D Project Archiving With Open Standards: Lessons From CAD/BIM

Much of the 3D project digital archiving literature to date has mainly centered on the curating of CAD and Building Information Models (BIM) from the architecture, engineering, and construction industries. Open standards initiatives, including IFC [14], STEP [15], and IGES [16] have been introduced in an attempt to mitigate the acute problems of comprehensive 3D project archiving and coherent model exchange that currently exist. CAD is a rapidly evolving area of software development. Products allow designers to create intricate, virtual, internal 3D models based upon proprietary mathematical algorithms and

format specifications. Variance among CAD software packages, however, with regard to such internal processing, and their outputs defines competitive advantage among vendors and hinders the adoption of open standards. As Smith [17] notes, even when models can be output into an open standard, the result incurs loss since "native 3D CAD file formats cannot be interpreted accurately in any but the original version of the original software product used to create the model."

With regard to photogrammetry, the current prospects for IFC, STEP, and IGES adoption are not much brighter. These standards were born within the CAD ecosystem of constructive solid geometry and internal parametric modeling. As a result, they are not currently supported within such photogrammetry processing or mesh editing software packages as PhotoScan or MeshLab [18], which instead deal more exclusively with the creation and editing of basic surface geometry and texture. Hence, though potentially feasible, the outlook to normalize photogrammetry project data to one of these open standards remains mostly unrealized.

Preservation Options For Photogrammetry-based 3D Data: What to Archive and Why

There remain, however, core preservation principles that can currently be tailored toward photogrammetry data sets. Given the rapidly advancing nature of 3D computational tools, it is essential that basic source data, sequentially built upon during the project, be preserved for potential sharing among users and for re-processing and editing by future software.

Following this paradigm, original 2D raster image sets should be archived, uncropped and not resized, in both a raw (e.g. DNG) and RGB-rendered (e.g. TIF) versions. In addition, final registered point cloud data should at a minimum also be archived in an ASCII format with text file extension along with at least one 3D graphics format like the openly documented and well supported OBJ [19]. 3D models should be similarly archived as OBJ [20][21], and VRML ISO/IEC 14772 [22] or VRML's successor, X3D ISO/IEC 19776 [23][24][25]. Vendor-neutral, point cloud data, when considered as a restricted subset of the final textured model, is important to archive since it is assumed that it will be converted with the greatest level of accuracy from the original processing software. On the other hand, textured model archiving, while potentially sacrificing exactness, attempts to more broadly preserve the most 3D information possible and the maximum potential functionality in an open format [26][27].

The creation and archiving of STL models should also be considered for basic, non-colored 3D printing purposes. For projects where potential 3D color printing is of a high preservation priority, the X3D standard in particular has exhibited consistent support among print exchange and vendor options [28][29] and is considered by the U.S. National Archives and Records Administration to be a preferred format for the transfer of permanent CAD records [30].

Figure 5. *3D print from photogrammetry-produced STL file (ABS print by Thomas Mealy from virtual model by author).*

It bears noting that OBJ, as 3D textured model format, requires external raster image (e.g. JPG) and MTL reference files in order to describe the material properties of a given OBJ's polygons [31][32]. Of the formats mentioned heretofore, PhotoScan can export ASCII text files and OBJ point clouds, STL basic geometry models, and OBJ, and VRML (.wrl) textured models. X3D currently enjoys support as import and export option in both MeshLab and Blender [33] but not in PhotoScan.

Finally, it is recommended that 3D objects should also be archived in a format that is easily manipulated and perceived in generic viewers [34][35]. Such presentations can act as visual summaries for users who may not want to conduct deeper explorations into complex content through dedicated 3D applications. As one example, basic PDF Reference v1.6 specification files and beyond can support fundamental manipulations through embedded web browser plugins and/or the free Adobe Acrobat Reader. In particular, the emerging PDF/E ISO 24517-1 standard (which is based upon PDF Reference v1.6) is seen to hold promise in this regard [36][37].

Yet current implementation problems exist. PhotoScan, for instance, offers PDF as one of its export options where a given 3D project model is embedded in the PDF file as an interactive U3D [38] object. The resulting model can be rotated, spun, panned and zoomed using Reader's tools and can potentially be archived together with a project's other point cloud and 3D model data. Though PhotoScan's PDF export option is easy to use and is certainly a welcomed and unique feature among 3D modeling software, it unfortunately results in non-conforming PDF files that fail subsequent Acrobat Preflight validation. Closer inspection reveals that these exports are nominally encoded as PDF v1.3 yet contain the more advanced 3D functionality first documented in the PDF v1.6 specification. Acrobat Preflight can certainly fix these files after they are created, but such conformance issues are particularly problematic when users' fundamental objectives include preservation actions efficiently carried out to scale and to format standard. Alternately, U3D files exported from PhotoScan can be embedded and saved into PDF/E files through a separate pipeline to Acrobat.
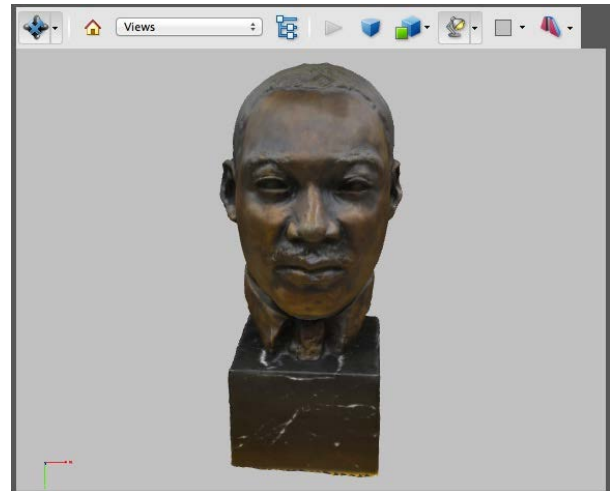

Figure 6. *Textured U3D model embedded in PDF/E file as viewed within Adobe Acrobat 10.1.13, (virtual model by author).*

Organizing Photogrammetry Data: Wrapper, Bundling, and Repository Options

Thinking beyond basic source images, point cloud, textured 3D model, and print-ready formats, overall project wrapping and/or bundling options should be considered for purposes of long term project continuity, file organization, and coherent transmission and storage. To start, it is recommended that 3D project data be archived in a format native to the software that created the original models in order to preserve them with the most robust and accurate data about their design [39][40][41]. As noted earlier, PhotoScan project files can be wrapped, compressed, and saved to the PSZ format. Utilized in this way, PSZ files can subsequently be read back and selectively decoded as an assemblage by PhotoScan, which can understand both the wrapper and the encoding of the encapsulated bitstreams [42].

Bundling [43], on the other hand, is more strictly a process of file aggregation. Simple ZIP archiving [44] is one such basic option for all of a given photogrammetry project's data (including wrapper files like PSZ). However, the Library of Congress' BagIt specification [45][46] additionally offers features that allow it to also act as a self-described bundling format. BagIt "bags" are named file system directories that can be created for photogrammetry-produced 3D objects. Such bags can encompass all project data including pre-created folders and individual files into a hierarchical BagIt "data" directory. Minimally included in a given bag is at least one manifest file that itemizes the filenames present in the "data" directory as well as their checksums. Descriptive project and analog object metadata can also be created and incorporated. Bag contents can be saved as either a file system directory or serialized and compressed into a single ZIP file. Once created, bags can be used for data transmission and/or archived as-is.
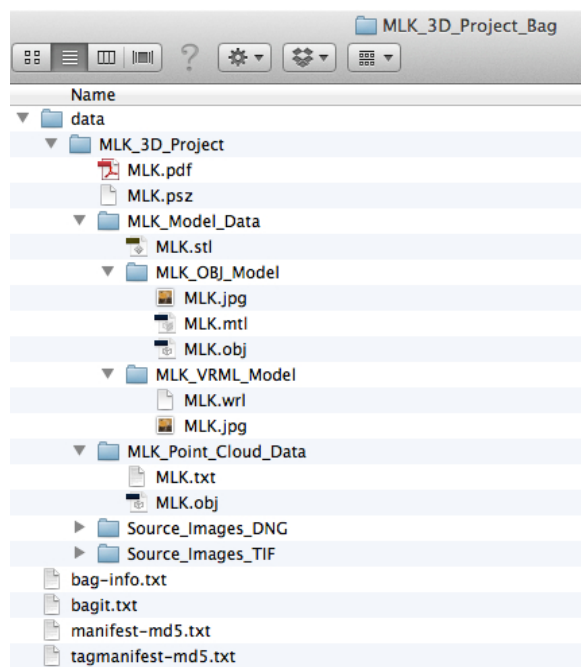
Figure 7. *What to archive and how to organize it: a sample hierarchical BagIt bag of recommended preservation formats for the MLK 3D model illustrated in Figure 6.*

It should be pointed out that the BagIt specification does not require nor prohibit the customized inclusion of detailed manifest information on the relationships among bag components or define how such information should be created [47]. Conversely, the proposed ISO/IEC 21320-1 "Document Container File" specification *is* expected to mandate the description of relationships among component files "either through a generic relationship representation or the use of prescribed application-specific naming conventions [48]." Based upon a constrained form of ZIP, ISO/IEC 21320-1 currently remains in committee draft stage. Yet the specification may eventually prove to be an adept, purpose-built bundling format for complex 3D data.

Finally, digital repositories can also directly play an organizational role in the preservation of 3D datasets. Platforms like Fedora host their own structural metadata schemas and can include customized "content models" that more explicitly define how associated files or *datastreams* should be related to one another. In practice, bundling formats can act as complementary transfer carriers to repositories of conforming data that are either ingested as-is or are further normalized to a repository's given 3D object content model.

Summary

3D data archiving remains a multifaceted web of decision points on file formats, their relational organization, packaging, and final storage. As cultural heritage institutions begin to more fully explore the possibilities of 3D modeling techniques and the outputs that result, it is natural to anticipate that a broadening literacy in 3D data curation will be needed. Much like 3D laser scanning, photogrammetry as an applied technology can encompass many intriguing potential use cases within these organizations. With a growing community of practitioners it is hoped that an increasingly informed and cohesive voice will further evolve among memory institutions in order to more directly assist and influence the ongoing development of 3D-related format standards and software tools.

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